DEVELOPMENT OF DISPLAY SYSTEM FOR NGV DISPENSER PANEL

MARZIAH BINTI MAHMOD

ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS

JUNE 2010

DEVELOPMENT OF DISPLAY SYSTEM FOR NGV DISPENSER PANEL

By

MARZIAH BINTI MAHMOD

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

DEVELOPMENT OF DISPLAY SYSTEM FOR NGV DISPENSER PANEL

By

Marziah binti Mahmod

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

(Dr. Nordin Saad)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Marziah

Marziah binti Mahmod

ABSTRACT

As a partial fulfillment of Final Year Project, this project is about "Development of Display System for NGV Dispenser Panel". A new technology in natural gas refueling system that uses "Time Optimal Control" with "Switching Time Optimization" has been developed [1]. A display panel for a dispenser that fit with this new technology is designed using PIC Microcontroller-Based Information Display. As for the expected result, an electronic circuit board that uses algorithm to display mass, price and rate of price for natural gas accumulated in the receiver using LCD backlit screen is fabricated. This report describes the research and development activities that have been carried out. The outcome of this work has shown that it is possible to use a programmable integrated circuit (PIC) microcontroller as an interface between NGV sensor and the information display system.

ACKNOWLEDGEMENT

I would like to thank Allah S.W.T for giving me the opportunity to do this final year project because of his mercies, I am successfully completed the project. Also, I would like to express my appreciation to Universiti Teknologi PETRONAS for providing the facilities and technical expertise to implement the project.

My appreciation is extended to my supervisor, Dr. Nordin Saad for the numerous hour of spending his time to assist in my project. His suggestions for this project are very valuable. Also, I would like to thank Dr. Mahidzal, my former supervisor during FYP 1 for his knowledge, experience, advice that had guided me along the project from a far. Next, I would like to thank Mrs Siti Hawa bt Hj Tahir and other technicians from Electrical and Electronics Department for their assistance during the development of the project.

Special thanks dedicated to my family and friends for their endless moral support along the development of the project. This project would not have been possible to finish without any help of many people who had involved.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

"Natural Gas is an organic compound that is found deep within the earth. It is a fossil fuel formed over millions of years of geological pressures and changes" [3]. Natural gas is an alternative of fuel sources like gasoline and diesel. Natural gas offers clean burning, economical and safe. The natural gas will be compressed and stored in a pressurized tank on the vehicles.

Natural gas is compressed and flows in to the higher pressure tank on vehicles through dispenser. Usually, the amount of dispensed gas is shown on a pressure gauge installed on the dispenser.

In this project, an electronic circuit board that uses algorithm to display mass, price and rate of price for natural gas accumulated in the receiver using LCD backlit screen. The current input signal would be from a flow meter sensor that produces 4-20 mA current, whilst a circuit board is to be designed which capable to produce output and represent mass, price and rate of price digitally.

1.2 Problem Statement

In natural gas refueling i.e., such as NGV, the gas must be transferred from higher pressure source to lower pressure receiver. The dispenser consists of several components, and one part of these is the display unit. The purpose of the display unit is to provide information about the price and the amount of gas transferred. The challenge in this project is to develop a display system that give accurate values in Ringgit and amount in Liter, also a cost effective and this is to be achieved using application of PIC microcontroller. After the display unit has been developed, it is expected to be mounted at the NGV prototype here in UTP.

1.3 Objectives

The objectives of this project are:

- To design and develop a current to voltage conversion circuitry from flow meter signal.
- To design and develop the programming which could display the amount of natural gas transferred.
- To design and develop a suitable display board that could be used for natural gas dispenser.

1.4 Scope of Study

The scopes of the project are:

- Development of a current to voltage conversion circuitry for natural gas refueling purposes
- Studying programming language that is suitable with PIC microcontroller
- Designing a suitable display board for the natural gas dispenser with switching algorithm using time optimization control (TOC) [2]

CHAPTER 2

LITERATURE REVIEW

2.1 Microcontroller

A microcontroller chip is a single-chip computer, including most of the computer's features but in limited size. Today, there are hundreds of different types of microcontroller, ranging from 8-pin devices to 40-pin or even 64- or higher pin devices.

2.1.1 Microcontroller Applications

A microcontroller chip is a single-chip computer, including most of the computer's features but in limited size. Today, there are hundreds of different types of microcontroller, ranging from 8-pin devices to 40-pin or even 64- or higher pin devices. Mainly, the microcontroller market now is dominated by Motorola and Microchip Technology. This embedded technology is now common in daily-used applications. Generally, they are:

- Consumer
- Automotive
- Office automation
- Telecommunications
- Industrial automation products

2.1.2 PIC16F877 Microcontroller

The PIC16F877 is an 8-bit, 40-pin microcontroller with the following features:

- Operation up to 20Mhz
- 8K flash program memory
- 368 bytes RAM memory
- 256 bytes electrically erasable programmable read-only memory (EEPROM) memory
- 15 types of interrupt
- 3 bits of parallel I/O capability
- 2 timers
- 10-bit, 8-channel A/D converter
- 2 analogue comparators
- 33 instructions
- programming in assembly or high-level language
- low cost

Most microcontrollers have built-in circuits necessary for computer applications. For example, PIC16F877 have A/D converter which is used to sample the external signals. They also have parallel input-output ports so that data can be read or as an input of the microcontroller. They also have timer and interrupt logic. Using these facilities, the microcontroller can be programmed to implement the control algorithm correctly. The microcontroller can be programmed using high level language such as BASIC or C compiler.

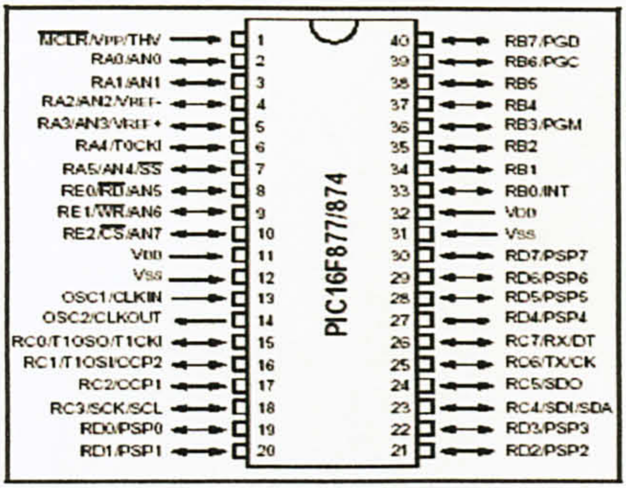


Figure 1: PIC 16F877 pin-outs

Most of the information display panels today are made of rapidly changing electronically control display. By using microcontroller, it gives flexibility of programmable logic in such application. Most commonly used PIC for display purposes is PIC16F877A. PIC16F877A can directly drive LCD (Liquid Crystal Display). Therefore, it does not require current driver for small application.

2.2 Instrumentation and Devices

2.2.1 Coriolis Flow Meter

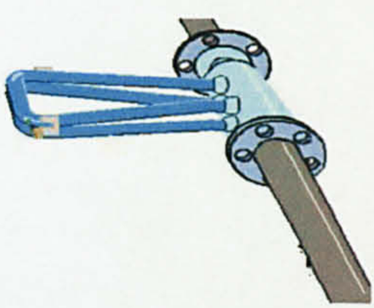


Figure 2: Coriolis flow meter

Coriolis flow meter is used to measure the mass flow rate and to determine natural gas in true mass [2]. They are various design of coriolis flow meter. One of the popular types is a U-shaped flow tube. The flow tube will vibrate at certain frequency by a magnetic device at the bend of the tube.

As the natural gas flows, it will experience a vertical movement and when it moving upward during its half cycle, the gas flowing into the meter will push the tube down. This will cause the tube to twist. The amount of twist is directly proportional to the mass flow rate of the gas flowing through the tube.

2.3 Interfacing Circuit

2.3.1 Current to Voltage Converter Circuit

In electronics, most of the devices use voltage as their input/output. In some cases such as measurements, a converter is needed when having a measuring instrument that uses voltage as its input.

The conversion can be as simple as using one resistor by applying an electrical current flow against the resistor as noted by Ohm's Law, V=IR. This can be illustrated as Figure 3 below [4].

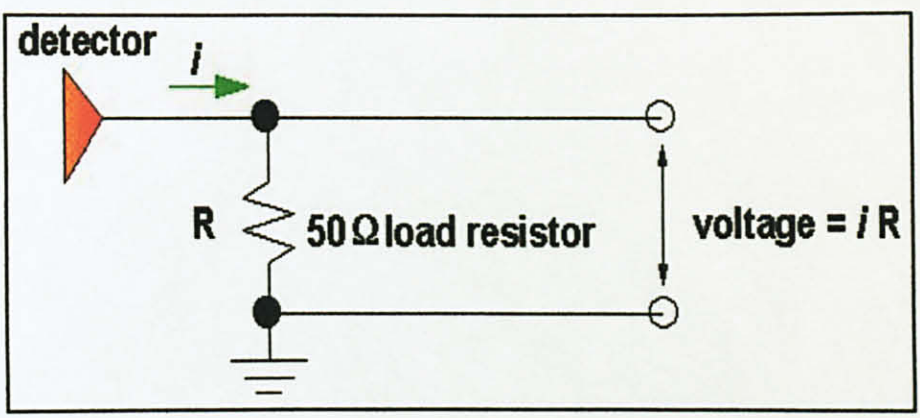


Figure 3: Simplest Current to Voltage Conversion Circuit

The current input signal is produced by a detector/sensor or transducer which in this project is a flow meter. This resistor is to drop the input current across the load resistor and voltage can be measure as output. The problem is the current always affected by the resistance since resistance decreasing current flow. So, the conversion will not be accurate [4].

The concept of operational amplifier can be used to perform the conversion. It is basically designed to perform mathematical operation. An amplifier is made of a gain block and a feedback network consists of resistor that determines the characteristics of the amplifier.

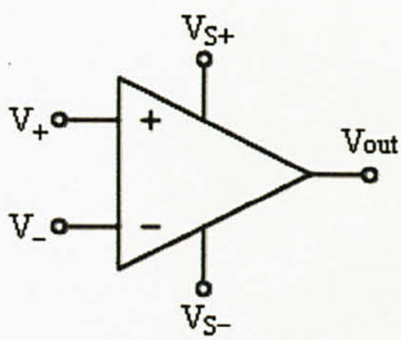


Figure 4: Operational Amplifier

V+ is the voltage of non-inverting terminal, while V- is the voltage of the inverting terminal. The voltage difference between these two terminals is called differential voltage. In Figure 5, such connection can be used to make the resistor become a current-to-voltage converter or vice versa.

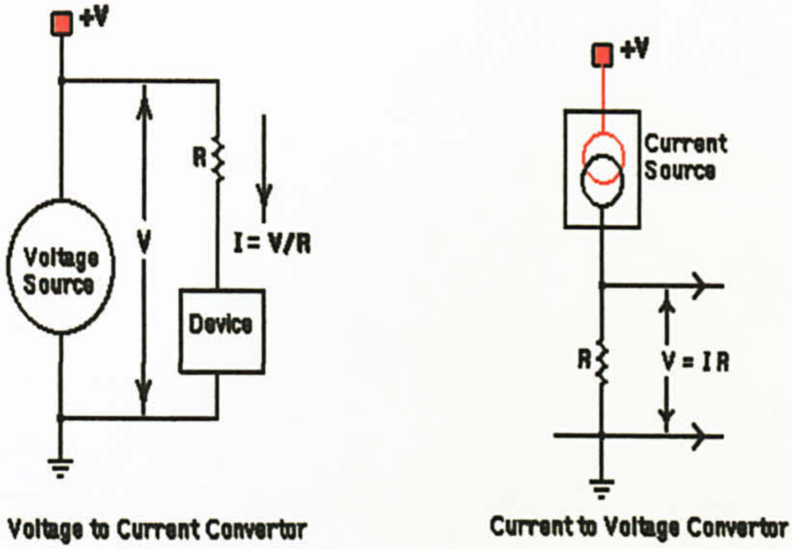


Figure 5: Resistor in Current to Voltage Conversion

Operational amplifier can give simple linear signal processing and a resistor for dissipating current. The resistance between the operational amplifier's input and output determines the voltage range for specific current signals. Figure below show the op amp can convert an input signal to the desired output voltage. An input current of 1 mA flows to the inverting input terminal through the 1K input resistor, R1.

The op amp will generate an output voltage of the opposite polarity, which will cause the 1mA to flow through the 10 K feedback resistor. Because the feedback resistor, R2 I ten times the value of the input resistor, it will require ten times the voltage to cause the same 1 mA to flow [4]

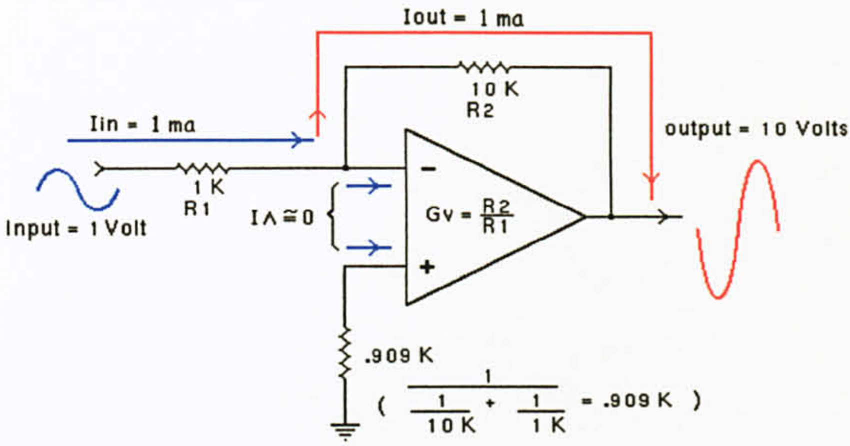


Figure 6: Operational Amplifier as Current to Voltage Converter

2.4 Output Devices

2.4.1 Liquid Crystal Display Module

LCD can be used in a lot of application in terms of providing useful interface for the user. The most common type of LCD is the Hitachi 44780 which provides simple interface between a processor and an LCD.

CHAPTER 3

METHODOLOGY

3.1 Procedures Identification

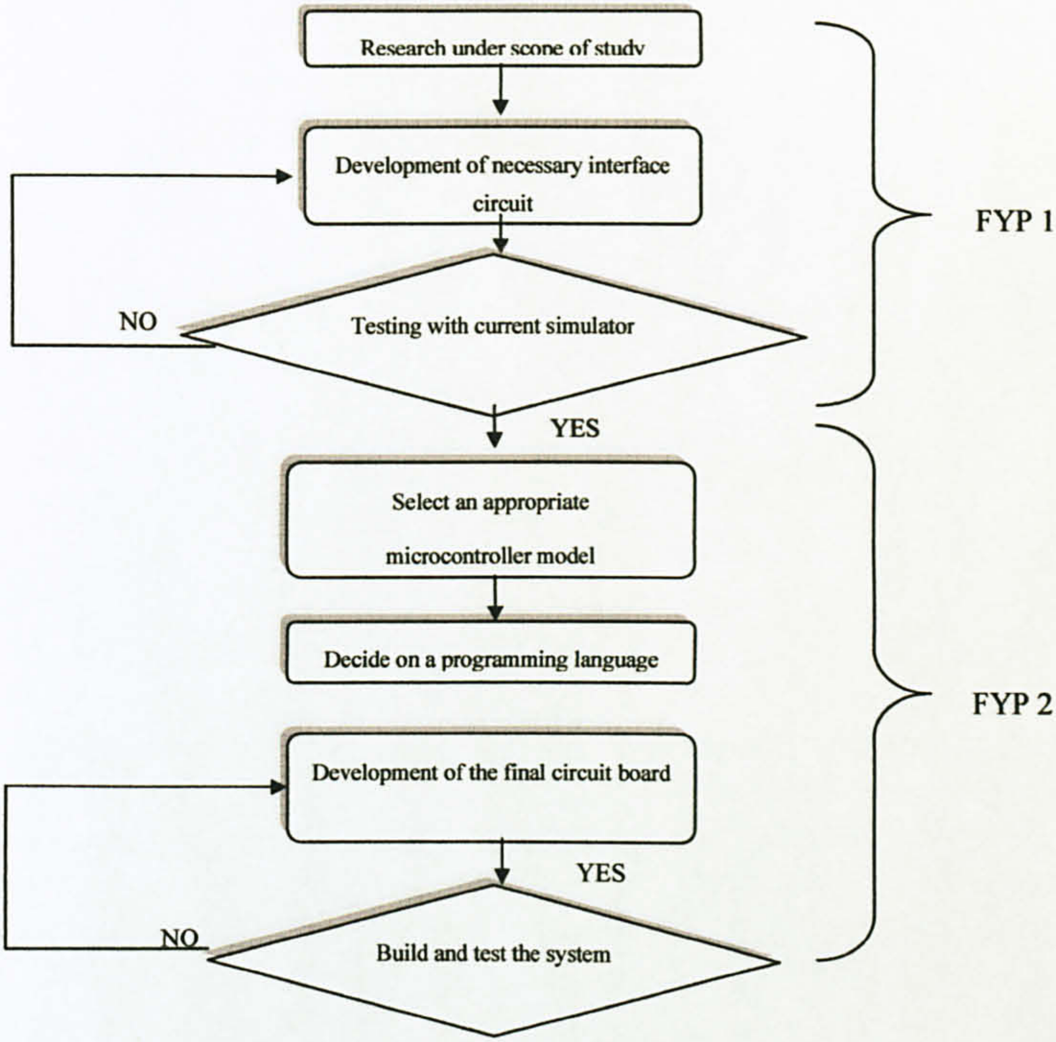


Figure 7: Procedures Identification

3.2 Tools Required

3.2.1 Hardware Requirements

1) Instrumentation and devices:
    a. Coriolis flow meter

2) Interfacing circuit:
    a. Flow meter to microcontroller

3) Display panel:
    a. Microcontroller
    b. LCD display

3.2.2 Software Requirements

1) PSpice
2) PICBasic – Microchip PIC programming software
3) UP00A USB Programmer - PIC Programmer Burner

3.3 System Overview

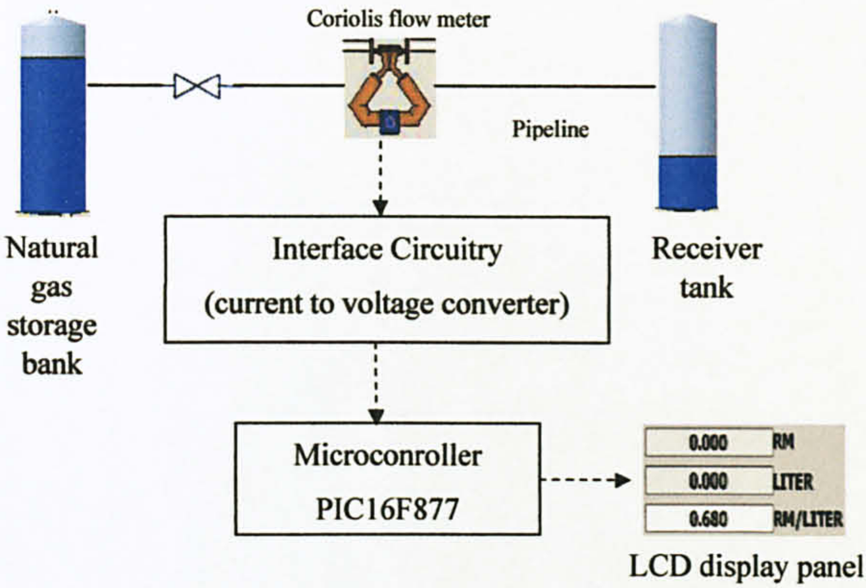


Figure 8: System Overview

Figure 8 shows the overview of the system. The natural gas will flow from higher pressure storage bank to the lower pressure receiver tank of the vehicle. When the natural gas flow through the pipeline, the Coriolis flow meter will sense the flow rate and give a current output (4-20mA) to the interfacing circuit. The interfacing circuit which is current to voltage converter will convert the 4-20mA current output to voltage. This voltage signal will be sent to the analogue to digital converter (ADC) pin of the microcontroller. Then, the microcontroller will calculate and display the volume as well as the price to be paid at the LCD display panel. The dispenser display panel is designed so it that can be implemented with the switching algorithm TOC which is being done by another FYP student.

3.4 System Identification

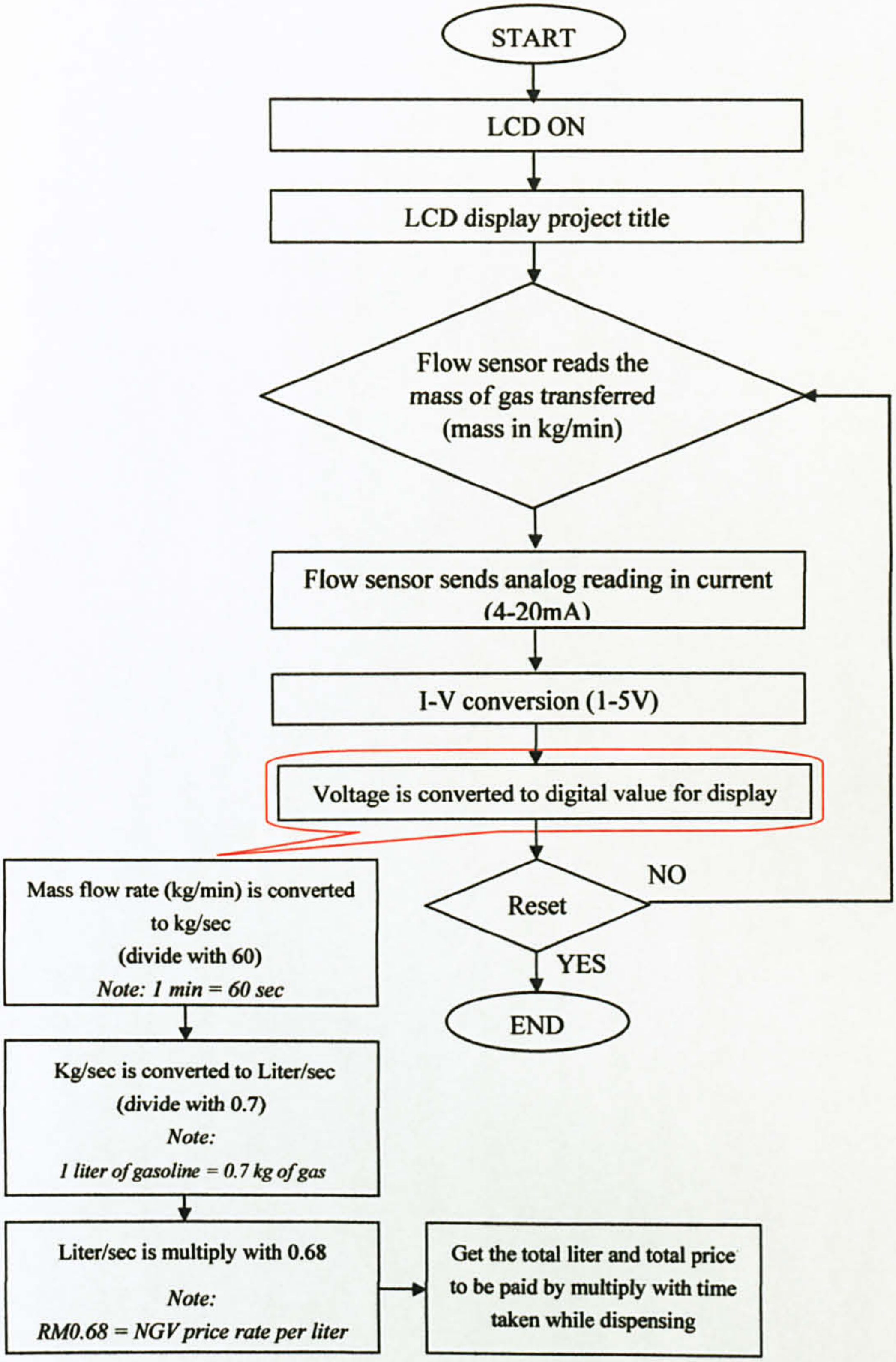


Figure 9: System Identification

3.5 Project Work

3.5.1 Current to Voltage Conversion Circuit

Measurement of natural gas refueling is based on a flow meter signal i.e., Coriolis flow meter. In some cases, the signal would be used as a control input for the natural gas refueling process. Since the microcontroller requires a voltage signal, a circuit must be designed to convert current signal from flow meter.

Before fabricating the circuit, a PSpice simulation is done to simulate the current conversion process. Figure 10 shows the current to voltage simulation that has already been tested using PSpice. The circuit is designed using the operational amplifier concept where an input current signal is converted back to a specific voltage range from a suitable resistor value as its feedback network.

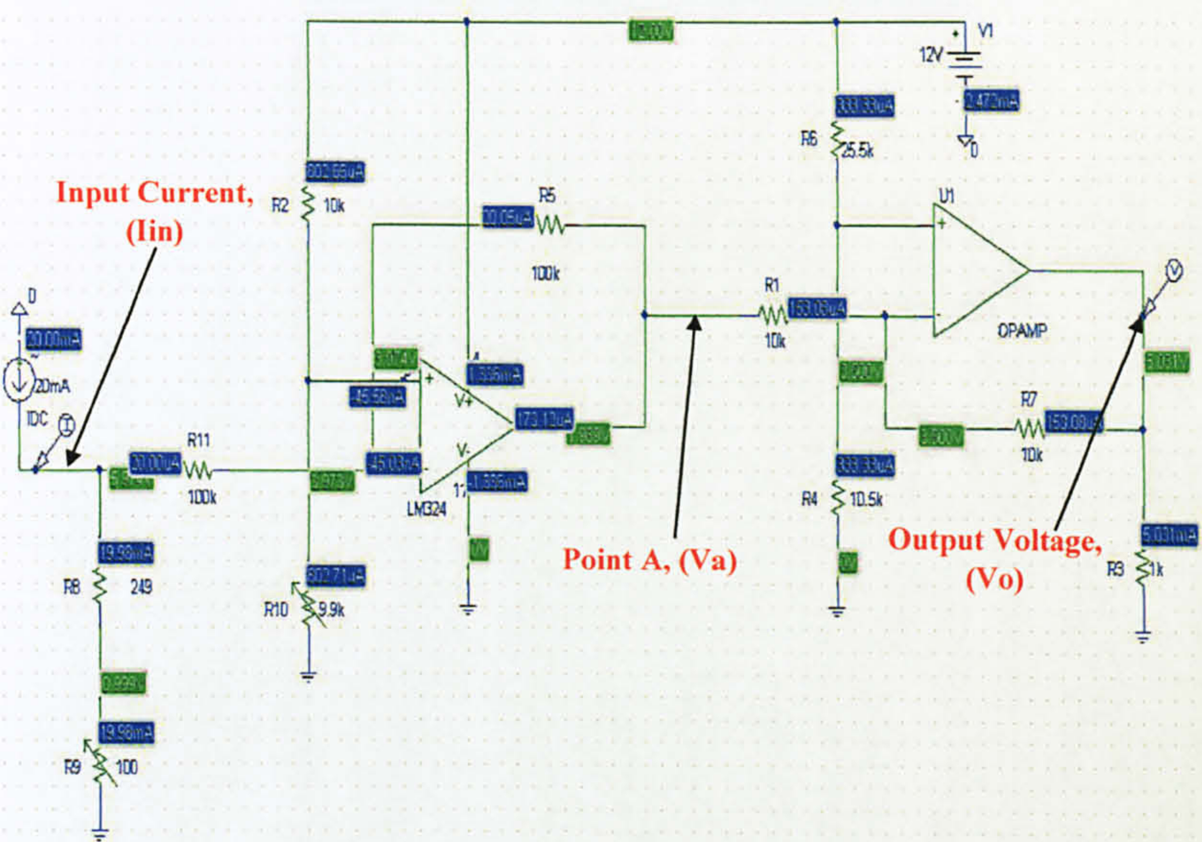


Figure 10: Simulation on Current to Voltage Converter Circuit using PSpice

Figure 11 shows the expected result after the simulation has been done. The range of current input is set to be from 4 mA to 20 mA. Voltage at point A, Va in schematic shown in Figure 10 is recorded as well as the output voltage, Vo.

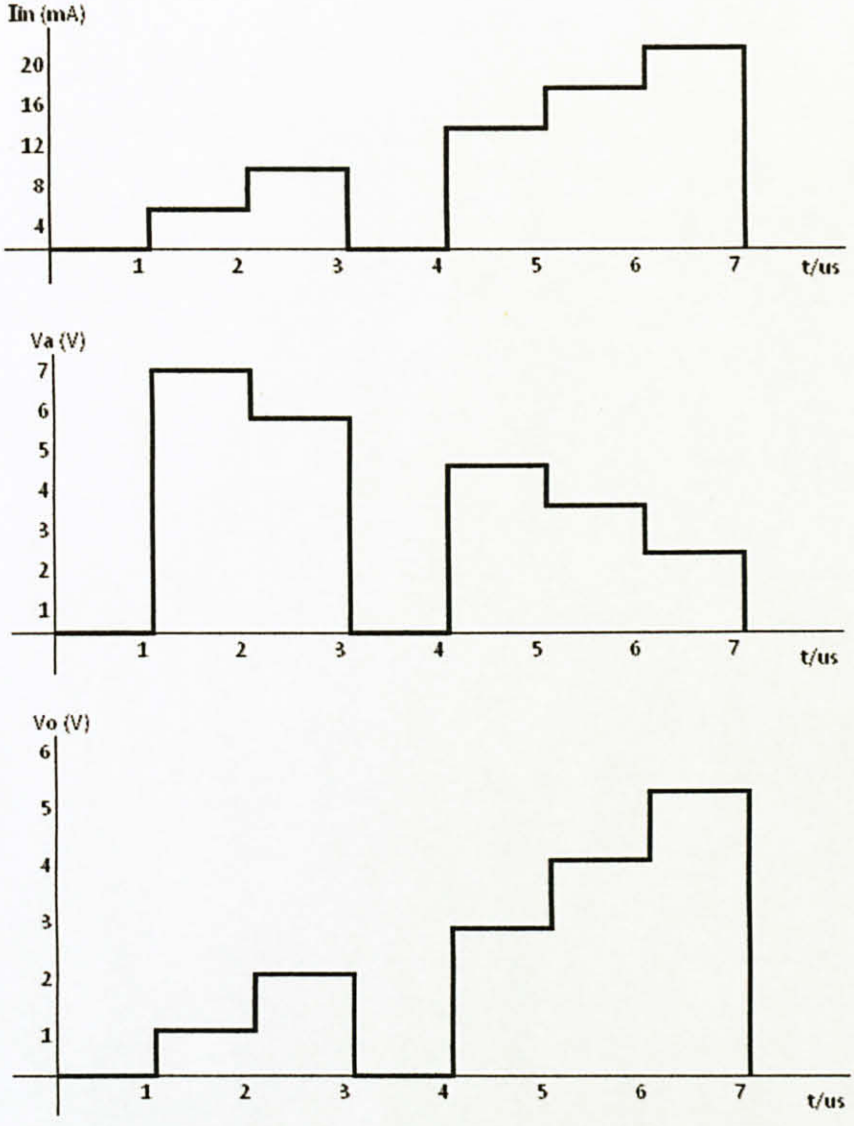


Figure 11: Simulation Results

3.5.2 Interfacing PIC16F877A with LCD

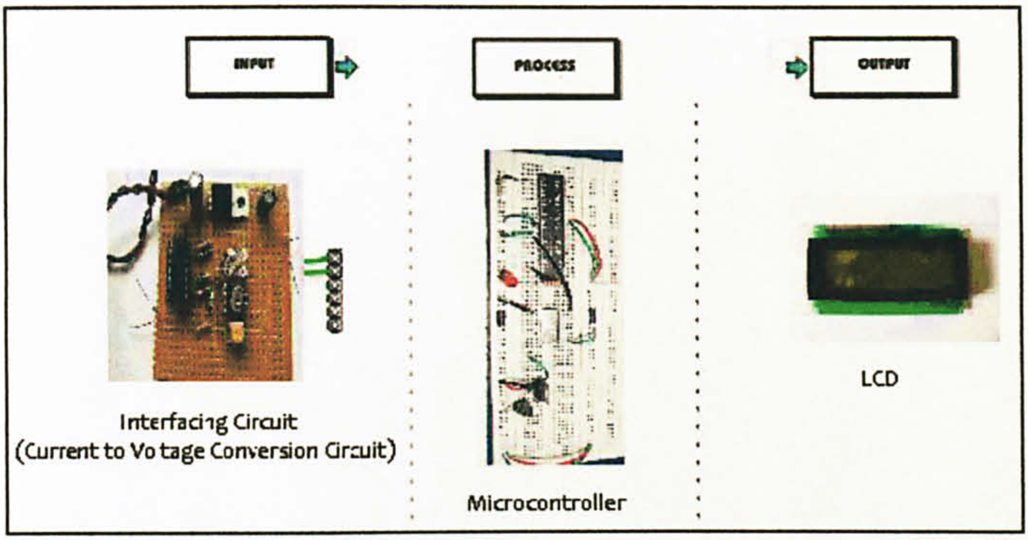


Figure 12: PIC Microcontoller

The design have one input which is in this project is the interfacing circuit. This input activates the microcontroller circuit. The interfacing circuit converts current signals (4-20 mA) that comes from a flow meter in to 1-5V. This 1-5V becomes the input to the microcontroller. Then, the microcontroller is programmed to process the input to give the desired output on the LCD.

To get started, there are certain steps and items prepared. The author has listed down the followings:

1. PIC microcontroller chip
2. USB PIC Programmer
3. Programming Language
4. PIC Programming/Burning Software
5. Computer
6. Common electronic components

3.5.2.1 PIC (Programmable Integrated Circuit)

The author has decided to use PIC16F877A due to the features and good memory. It also seems to be the most popular PIC and suitable to most of other application and cheap where it cost around RM 21.00.

3.5.2.2 USB PIC Programmer

As for the programmer, any model can be used but one with wide variety of PICs' is suggested. The author used UP00A USB Programmer from Cytron Technologies as shown in Figure 13.

Figure 13: UP00A USB Programmer

3.5.2.3 Programming Editor

There are many types of editor can be used such as PICBasic, MPLab, Notepad++ and also a free editor that can easily downloaded from internet, JAL Edit. Different editor used different language style. In this project, the author chooses to use PICBasic.

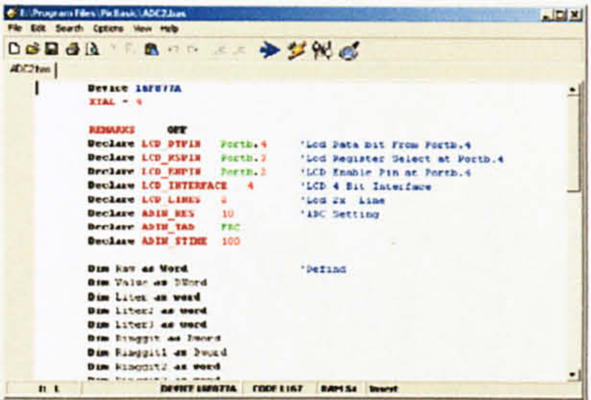


Figure 14: PICBasic screenshot

3.5.2.4 PIC Programmer/Burning Software

This PIC Programmer is software used to load the program that has been developed using editor. Usually, the software came with the programmer. In this project, WinPic800 is used.

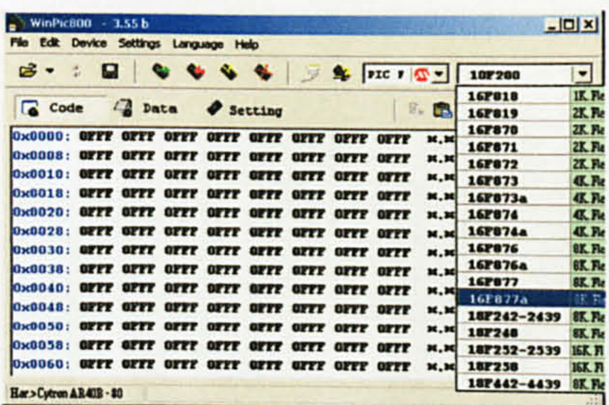


Figure 15: WinPic800 screenshot

3.5.2.5 LCD

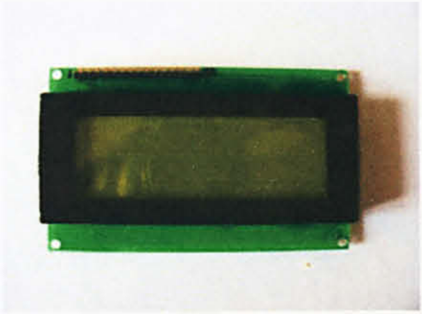


Figure 16: LCD JHD 204A

As for the LCD, JHD 204A is chosen to be the output device. This LCD has 4 lines with 20 characters. So that it can display the desired output information, Ringgit (RM), Liter (L) and Ringgit per Liter (RM/L). In order to complete the LCD interfacing circuitry, the author focused to study the type of LCD used (JHD 204A) and also the PIC (PIC16F877A). Table 1 shows the pin assignment for JHD 204A.

Table 1: JHD204A Pinouts

Pin NO.	Symbol	Function		Remark
1	GND	Power supply	0V	
2	Vdd		+5V	
3	V5		For LCD	Variable
4	RS	Register Select(H-Data,L-Instruction)		
5	R/W	Read/Write L-MPU to LCM,H-LCM to MPU		
6	E	Enable		
7	DB0	Data bus bit 0		
8	DB1	Data bus bit 1		
9	DB2	Data bus bit 2		
10	DB3	Data bus bit 3		
11	DB4	Data bus bit 4		
12	DB5	Data bus bit 5		
13	DB6	Data bus bit 6		
14	DB7	Data bus bit 7		
15	A	Anode of LED Unit		
16	K	Cathode of LED Unit		

For convenience when building the whole on connection on breadboard, a male connector was soldered on the LCD which shown is Figure 17.

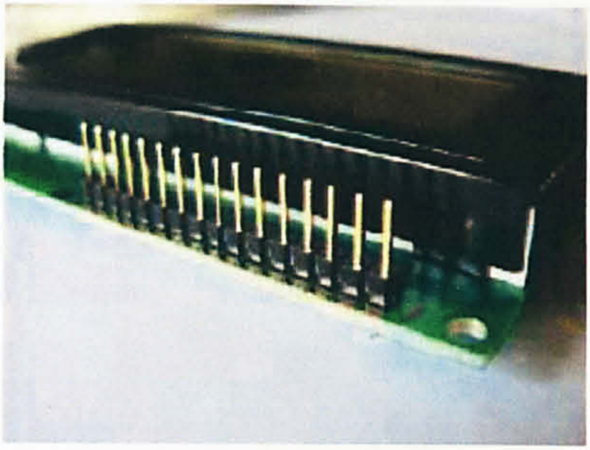


Figure 17: Male Connector on LCD

The LCD is then connected accordingly in schematic shown in Figure 18. The author chose to access the LCD with *4-bit interfaces* which require less pin (4-pin). Therefore, pin 11, 12, 13 and 14 on JHD204A which represent DB1, DB2, DB3 and DB4 *(refer to Table 1).* As the LCD is used only for displaying purpose, the R/W pin is to be grounded (pin 5).

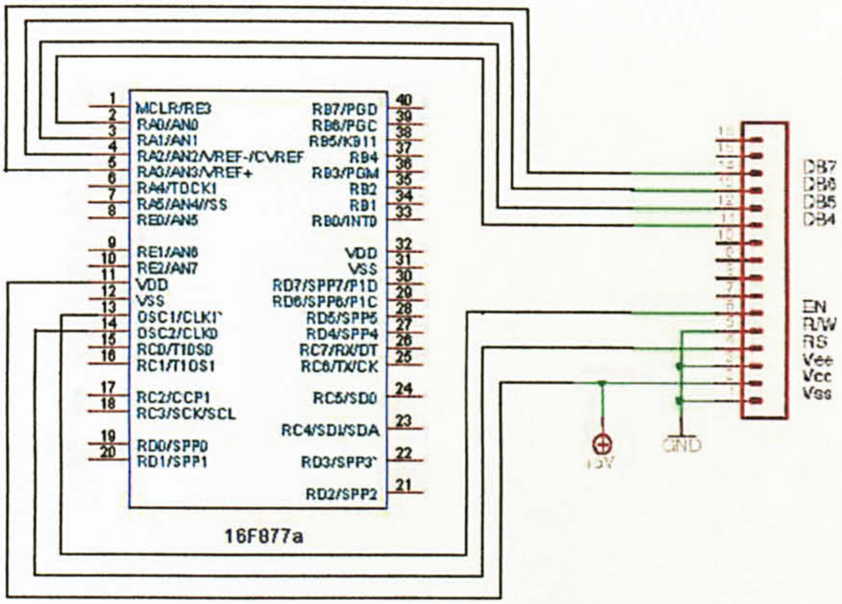


Figure 18: Schematic for Interfacing JHD204A with PIC16F877A

3.5.3 Programming

At this stage, the program for conversion system is developed using PICBasic. The author has divided the program into two main parts which analogue to digital converter (ADC) and LCD Display. ADC program is function to convert the analogue signal produce from the flow meter (current simulator is used in this project), while the LCD program is function to display the required information which are Ringgit (RM), Liter (L) and Ringgit per Liter (RM/L).

3.6 Prototype

At this stage, after completing the design and simulating, the prototype is developed. The current to voltage converter (I – V) circuit will be connected to the LCD interfacing circuit. LCD interfacing circuit will read signal from I –V circuit and the microcontroller will do the conversion and display the required information on the LCD.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Current to voltage converter

An interfacing circuit is needed to convert the current output from flow meter to voltage ranges between to 1-5V as the PIC 16F877 can read input voltage between these ranges. The output of this circuit will goes into one of the Analogue to Digital converter (ADC) pin of the PIC16F877.

Based on theory application, LM 324 will convert the 4-20mA current input to 1-5V voltage. The conversion can be simplified in Table 2.

Table 2: Result of I -V Conversion Circuit

I_{in} (miliampere)	V_{out} calculated (voltage)	V_{out} measured (voltage)
4	1.0	0.750
8	2.0	1.883
12	3.0	2.996
16	4.0	3.916
20	5.0	4.977

Based on the data, the graph of measured and calculated output voltage versus frequency is plotted.

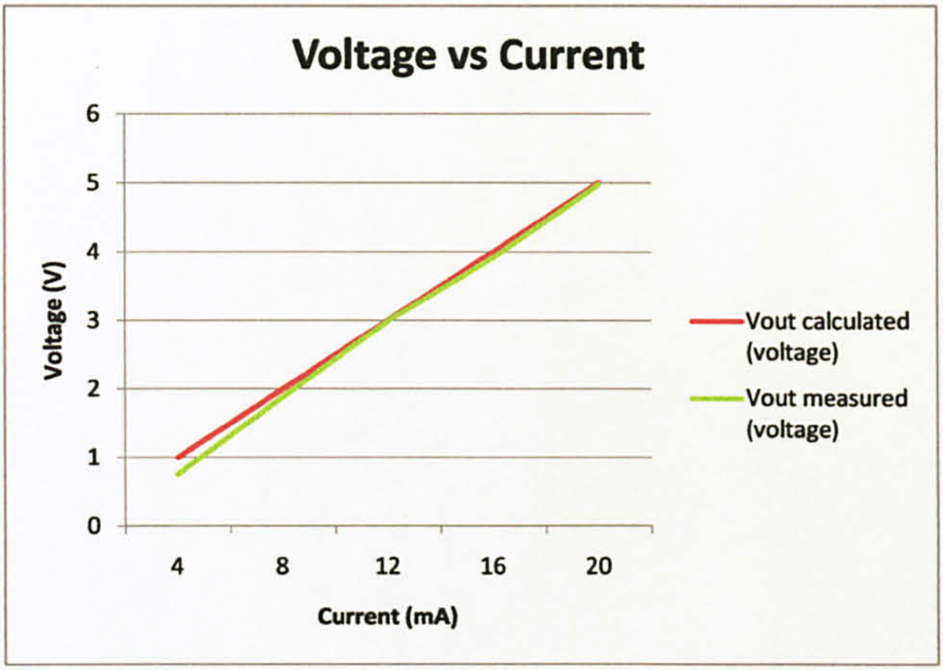


Figure 19 : Graph for measured and calculated output voltage versus current

When fabricating the interface circuit, there were some amendments being done to ensure its efficiency. For example, a regulator is added to the 12V DC power supply to provide an average DC output voltage at a desired level despite having a fluctuates input voltage sources. There also some tuning has been done to meet the interface circuit requirements.

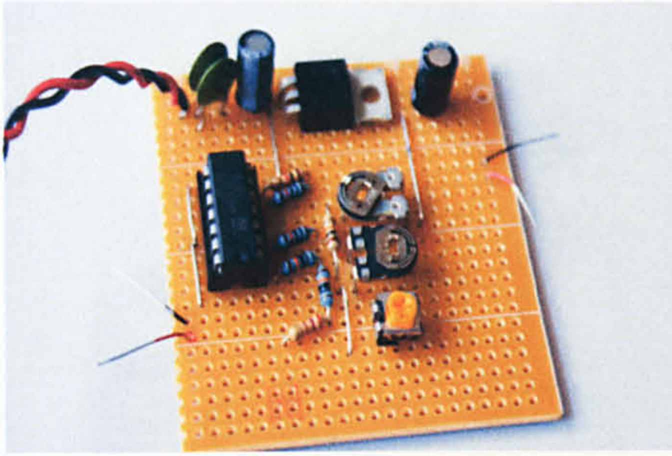
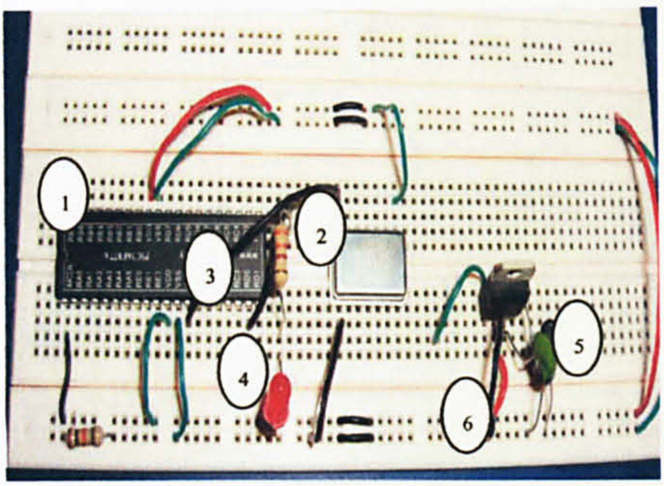


Figure 20: Current to Voltage Conversion Circuit

4.2 Microcontroller Based - LCD Display Panel Circuitry



1. PIC16F877A
2. Crystal Oscillator (20MHZ)
3. Voltage Regulator
4. LED
5. Capacitor
6. Safety wire

Figure 21: Microcontroller LED Test Circuit

The microcontroller circuit shown in Figure 21 has been fabricated to test the circuit is well functioning. Before connecting the circuit to the power supply, all the connection must be double check otherwise the PIC might burn.

The PIC can only takes 5V as its voltage limit. As precaution, the author connects one wire for safety which is connected to the PIC. The safety wire is disconnected while the circuit is powered on. A multi meter is used to check the voltage flows into the circuit. This is to show that the voltage regulator is working. Once it is confirmed that the voltage is sufficient, the safety wire is then connected.

A test program loaded is loaded to the PIC and successfully executed. The Led is turned ON when it is connected to pin RB0 as RB0 is set to be "high". Reading on the multi meter shows that the voltage regulator circuit is doing well by limiting the voltage for not to exceed 5V even though the voltage from the supply is 8V.

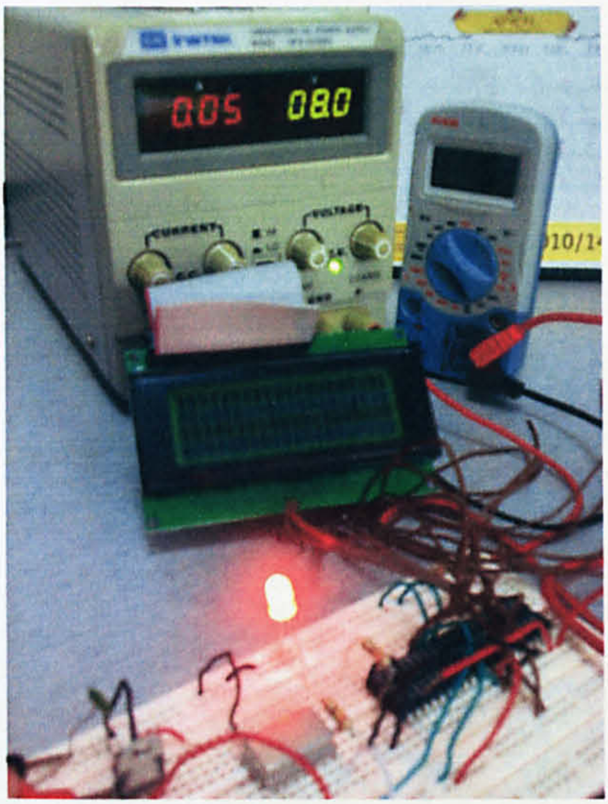


Figure 22: LED Test Output

4.3 Integrating I–V Conversion Circuit with LCD Interfacing Circuit

A prototype has been developed as shown in Figure 23. The PIC is loaded with equivalent program and a five point check sequential test is being done and the results are recorded in Table 3. A current simulator is used instead of the real sensor.

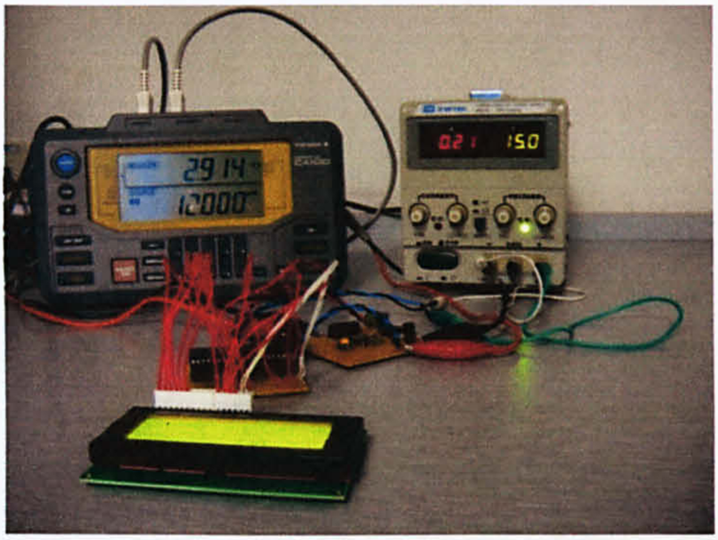


Figure 23: Prototype

In Figure 24, the LCD showed the required information, RM, Liter, and RM/L.

Figure 24: Information Display

Table 3: Overall Result

Current (mA)	Voltage (V)		Liter		Ringgit	
(injected)	calculated	measured	calculated	displayed	calculated	displayed
4.00	1.0	0.759	0.1084	0.1047	0.0737	0.0711
8.00	2.0	1.843	0.2633	0.2584	0.1790	0.1757
12.00	3.0	2.925	0.4179	0.4121	0.2842	0.2802
16.00	4.0	4.003	0.5718	0.5728	0.3889	0.3895
20.00	5.0	5.083	0.7261	0.7125	0.4937	0.4845
16.00	4.0	4.002	0.5717	0.5728	0.3888	0.3895
12.00	3.0	2.923	0.4176	0.4191	0.2840	0.2849
8.00	2.0	1.842	0.2631	0.2584	0.1790	0.1757
4.00	1.0	0.760	0.1086	0.1047	0.0738	0.0711

From Table 3, column 2 and 3 from left shows calculated and measured I-V conversion values but there is still error at the 4mA reading that need to be corrected. The overall results although not shown accurate reading but still acceptable since the values is linear and close to the expected values. Meanwhile, column 4 and 6 shows the result that displayed on the LCD panel. A graphical result is shown in APPENDIX E.

Then, the reading in per sec is multiply by the time taken while dispensing to get the total liter of natural gas and also the total price need to be paid. For example,

Liter/sec = 0.4121 liter/sec

RM/sec = Liter/sec x 0.68
= 0.4121 x 0.68
= RM 0.2802 per sec

Assume that 60 sec is the dispensing time,

Total Liter = Liter/sec x time taken
= 0.4121 x 60sec
= 24.726 liter

Total Price = Total Liter x 0.68
= RM 16.814

Figure 25: Total Value Display

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The aim of this project has been to design and implement a display panel for dispenser of an NGV refueling system that would provide a minimum switching time and a faster filling rate for NGV refueling using TOC refueling algorithm.

It discusses fundamental issues in the development of the simulation model for the display system for NGV dispenser and the methodology of the design stages. This report has covered two main issues: development of the panel and the circuit design. In particular, it has been organized to answer questions such as,

- what type of circuit is required to produce display flow meter signal for an natural gas refueling system.
- how to implement the method and build a simulation model for the refueling purpose.
- how to specify problems and scenarios to be analyzed (the relevant experimental design), and
- how to extract useful information for circuit development.

The outcome of this project is to design and develop the prototype of a display system for an NGV dispenser panel. The objective is achieved by using a suitable method of converting the analog signal from sensor to digital signal for display purposes. PIC microcontroller had become the main interface for the conversion procedures. However, the signal from real sensor becomes a limitation of this project which is to be work out by other student.

5.2 Recommendation

Even though this project has achieved the objectives, there are other improvement can be made to increase its accuracy and efficiency. For this project, instead of simulating the current signal using current simulator as the input signal from flow sensor, an actual signal from real flow sensor can be used so the that real time readings can be recorded. Also, a better tuning for I-V converter circuit is required to get more accurate readings.

REFERENCES

[1] Mahidzal Dahari, Nordin Saad, Mohamed Ibrahim Abdul Mutalib, NorAzizah Hisham *"Design and Implementation of a Minimum Switching Time Transitions for NGV Refueling"* IANGV Conference, Cairo, Egypt, 2006.

[2] Mahidzal Dahari, *"Switching Time Optimization via Time Optimal Control for NGV Refueling"* MSc Thesis submitted for Electrical & Electronic Engineering, Universiti Technology of PETRONAS, June 2006

[3] CNG Introduction

http://www.mckenziecorp.com/dehydration.htm

[4] Current to Voltage Conversion Circuit

http://elchem.kaist.ac.kr/vt/chem-ed/electron/circuits/itov.htm

[5] Operational Amplifier

http://www.williamson-labs.com/480_opam.htm

[6] Wikipedia homepage:

http://en.wikipedia.org/wiki/Current-to-voltage_converter

[7] PIC Microcontroller-Based Information Display panel

https://classshares.student.usp.ac.fj/EE313/2009%20EE313/Projects/

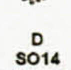
APPENDICES

APPENDIX A

LM 324 LOW POWER QUAD OPERATIONAL AMPLIFIERS

- WIDE GAIN BANDWIDTH : 1.3MHz
- INPUT COMMON-MODE VOLTAGE RANGE INCLUDES GROUND
- LARGE VOLTAGE GAIN : 100dB
- VERY LOW SUPPLY CURRENT/AMPLI : 375μA
- LOW INPUT BIAS CURRENT : 20nA
- LOW INPUT OFFSET VOLTAGE : 5mV max. (for more accurate applications, use the equivalent parts LM124A-LM224A-LM324A which feature 3mV max.)
- LOW INPUT OFFSET CURRENT : 2nA
- WIDE POWER SUPPLY RANGE :
  SINGLE SUPPLY : +3V TO +30V
  DUAL SUPPLIES : ±1.5V TO ±15V

N
DIP14
(Plastic Package)



D
SO14
(Plastic Micropackage)

P
TSSOP14
(Thin Shrink Small Outline Package)

DESCRIPTION

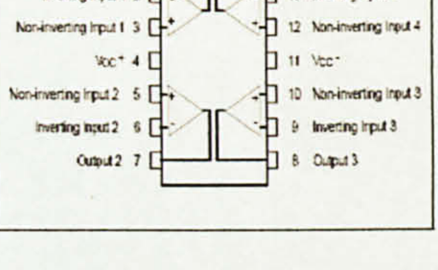
These circuits consist of four independent, high gain, internally frequency compensated operational amplifiers. They operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

ORDER CODE

Part Number	Temperature Range	Package		
		N	D	P
LM124	-55°C, +125°C	•	•	•
LM224	-40°C, +105°C	•	•	•
LM324	0°C, +70°C	•	•	•
Example : LM224N				

N = Dual in Line Package (DIP)
D = Small Outine Package (SO) - also available in Tape & Reel (DT)
P = Thin Shrink Small Outline Package (TSSOP) - only available in Tape &Reel (PT)

PIN CONNECTIONS (top view)



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter		LM124	LM224	LM324	Unit
V_{CC}	Supply voltage			±16 or 32		V
V_i	Input Voltage			-0.3 to +32		V
V_{id}	Differential Input Voltage [1]			+32		V
P_{tot}	Power Dissipation	N Suffix D Suffix	500	500 400	500 400	mW mW
	Output Short-circuit Duration [2]			Infinite		
I_{in}	Input Current [3]		50	50	50	mA
T_{oper}	Opearting Free-air Temperature Range		-55 to +125	-40 to +105	0 to +70	°C
T_{stg}	Storage Temperature Range			-65 to +150		°C

1. Either or both input voltages must not exceed the magnitude of V_{CC}^+ or V_{CC}^-.
2. Short-circuits from the output to VCC can cause excessive heading if V_{CC} > 15V. The maximum output current is approximately 40mA independent of the magnitude of V_{CC}. Destructive dissipation can result from simultaneous short-circuit on all amplifiers.
3. This input current only exists when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistor becoming forward biased and thereby acting as input diodes clamps. In addition to this diode action, there is also NPN parasitic action on the IC chip. this transistor action can cause the output voltages of the Op-amps to go to the V_{CC} voltage level (or to ground for a large overdrive) for the time duration than an input is driven negative.
   This is not destructive and normal output will set up again for input voltage higher than -0.3V.

ELECTRICAL CHARACTERISTICS

V_{CC}^{+} = +5V, V_{CC}^{-}= Ground, V_o = 1.4V, T_{amb} = +25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{io}	Input Offset Voltage - note [1] T_{amb} = +25°C LM324 $T_{min} \leq T_{amb} \leq T_{max}$ LM324		2	5 7 7 9	mV
I_{io}	Input Offset Current T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$		2	30 100	nA
I_{ib}	Input Bias Current - note [2] T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$		20	150 300	nA
A_{vd}	Large Signal Voltage Gain V_{CC}^{+} = +15V, R_L = 2kΩ, V_o = 1.4V to 11.4V T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	50 25	100		V/mV
SVR	Supply Voltage Rejection Ratio ($R_s \leq$ 10kΩ) V_{CC}^{+} = 5V to 30V T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	65 65	110		dB
I_{CC}	Supply Current, all Amp, no load T_{amb} = +25°C V_{CC} = +5V V_{CC} = +30V $T_{min} \leq T_{amb} \leq T_{max}$ V_{CC} = +5V V_{CC} = +30V		0.7 1.5 0.8 1.5	1.2 3 1.2 3	mA
V_{icm}	Input Common Mode Voltage Range V_{CC} = +30V - note [3] T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	0 0		V_{CC} -1.5 V_{CC} -2	V
CMR	Common Mode Rejection Ratio ($R_s \leq$ 10kΩ) T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	70 60	80		dB
I_{source}	Output Current Source (V_{id} = +1V) V_{CC} = +15V, V_o = +2V	20	40	70	mA
I_{sink}	Output Sink Current (V_{id} = -1V) V_{CC} = +15V, V_o = +2V V_{CC} = +15V, V_o = +0.2V	10 12	20 50		mA µA
V_{OH}	High Level Output Voltage V_{CC} = +30V T_{amb} = +25°C R_L = 2kΩ $T_{min} \leq T_{amb} \leq T_{max}$ T_{amb} = +25°C R_L = 10kΩ $T_{min} \leq T_{amb} \leq T_{max}$ V_{CC} = +5V, R_L = 2kΩ T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	26 26 27 27 3.5 3	27 28		V

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{OL}	Low Level Output Voltage ($R_L = 10k\Omega$) $T_{amb} = +25°C$ $T_{min} \leq T_{amb} \leq T_{max}$		5	20 20	mV
SR	Slew Rate $V_{CC} = 15V$, $V_i = 0.5$ to $3V$, $R_L = 2k\Omega$, $C_L = 100pF$, unity Gain		0.4		V/μs
GBP	Gain Bandwidth Product $V_{CC} = 30V$, $f = 100kHz$, $V_{in} = 10mV$, $R_L = 2k\Omega$, $C_L = 100pF$		1.3		MHz
THD	Total Harmonic Distortion $f = 1kHz$, $A_v = 20dB$, $R_L = 2k\Omega$, $V_o = 2V_{pp}$, $C_L = 100pF$, $V_{CC} = 30V$		0.015		%
e_n	Equivalent Input Noise Voltage $f = 1kHz$, $R_s = 100\Omega$, $V_{CC} = 30V$		40		$\frac{nV}{\sqrt{Hz}}$
DV_{io}	Input Offset Voltage Drift		7	30	μV/°C
DI_{lio}	Input Offset Current Drift		10	200	pA/°C
V_{o1}/V_{o2}	Channel Separation - note 4) $1kHz \leq f \leq 20kHZ$		120		dB

1. $V_o = 1.4V$, $R_s = 0\Omega$, $5V < V_{CC}^+ < 30V$, $0 < V_{ic} < V_{CC}^+ - 1.5V$
2. The direction of the input current is out of the IC. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.
3. The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V. The upper end of the common-mode voltage range is $V_{CC}^+ - 1.5V$, but either or both inputs can go to +32V without damage.
4. Due to the proximity of external components insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

APPENDIX B

MICROCONTROLLER PIC16F877A

Devices Included in this Data Sheet:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

High-Performance RISC CPU:

- Only 35 single-word instructions to learn
- All single-cycle instructions except for program branches, which are two-cycle
- Operating speed: DC – 20 MHz clock input
  DC – 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during Sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) – 8 bits wide with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Analog Features:

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)
- Brown-out Reset (BOR)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (VREF) module
  - Programmable input multiplexing from device inputs and internal voltage reference
  - Comparator outputs are externally accessible

Special Microcontroller Features:

- 100,000 erase/write cycle Enhanced Flash program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Data EEPROM Retention > 40 years
- Self-reprogrammable under software control
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Single-supply 5V In-Circuit Serial Programming
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving Sleep mode
- Selectable oscillator options
- In-Circuit Debug (ICD) via two pins

CMOS Technology:

- Low-power, high-speed Flash/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Commercial and Industrial temperature ranges
- Low-power consumption

Device	Program Memory		Data SRAM (Bytes)	EEPROM (Bytes)	I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8/16-bit	Comparators
	Bytes	# Single Word Instructions						SPI	Master I²C			
PIC16F873A	7.2K	4096	192	128	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F874A	7.2K	4096	192	128	33	8	2	Yes	Yes	Yes	2/1	2
PIC16F876A	14.3K	8192	368	256	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F877A	14.3K	8192	368	256	33	8	2	Yes	Yes	Yes	2/1	2

Pin Diagrams

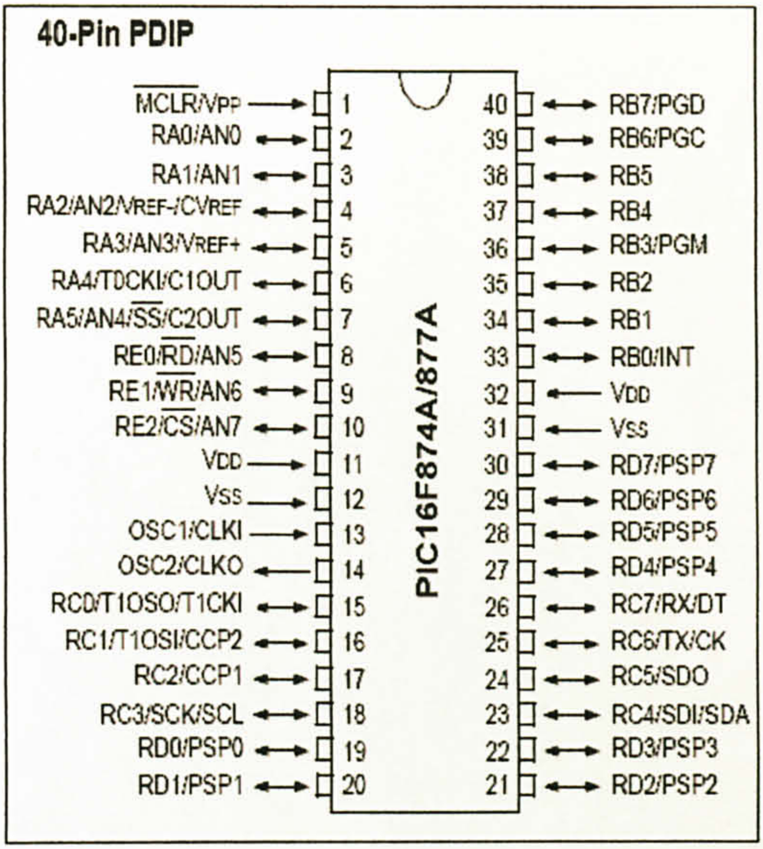


TABLE 1-3: PIC16F874A/877A PINOUT DESCRIPTION

Pin Name	PDIP Pin#	PLCC Pin#	TQFP Pin#	QFN Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKI	13	14	30	32		ST/CMOS[4]	Oscillator crystal or external clock input.
OSC1					I		Oscillator crystal input or external clock source input. ST buffer when configured in RC mode; otherwise CMOS.
CLKI					I		External clock source input. Always associated with pin function OSC1 (see OSC1/CLKI, OSC2/CLKO pins).
OSC2/CLKO	14	15	31	33		—	Oscillator crystal or clock output.
OSC2					O		Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO					O		In RC mode, OSC2 pin outputs CLKO, which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
$\overline{MCLR}$/VPP	1	2	18	18		ST	Master Clear (input) or programming voltage (output).
$\overline{MCLR}$					I		Master Clear (Reset) input. This pin is an active low Reset to the device.
VPP					P		Programming voltage input.
							PORTA is a bidirectional I/O port.
RA0/AN0	2	3	19	19		TTL	
RA0					I/O		Digital I/O.
AN0					I		Analog input 0.
RA1/AN1	3	4	20	20		TTL	
RA1					I/O		Digital I/O.
AN1					I		Analog input 1.
RA2/AN2/VREF-/CVREF	4	5	21	21		TTL	
RA2					I/O		Digital I/O.
AN2					I		Analog input 2.
VREF-					I		A/D reference voltage (Low) input.
CVREF					O		Comparator VREF output.
RA3/AN3/VREF+	5	6	22	22		TTL	
RA3					I/O		Digital I/O.
AN3					I		Analog input 3.
VREF+					I		A/D reference voltage (High) input.
RA4/T0CKI/C1OUT	6	7	23	23		ST	
RA4					I/O		Digital I/O – Open-drain when configured as output.
T0CKI					I		Timer0 external clock input.
C1OUT					O		Comparator 1 output.
RA5/AN4/$\overline{SS}$/C2OUT	7	8	24	24		TTL	
RA5					I/O		Digital I/O.
AN4					I		Analog input 4.
$\overline{SS}$					I		SPI slave select input.
C2OUT					O		Comparator 2 output.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured in RC Oscillator mode and a CMOS input otherwise.

TABLE 1-3: PIC16F874A/877A PINOUT DESCRIPTION (CONTINUED)

Pin Name	PDIP Pin#	PLCC Pin#	TQFP Pin#	QFN Pin#	I/O/P Type	Buffer Type	Description
							PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	9		TTL/ST[1]	
RB0					I/O		Digital I/O.
INT					I		External interrupt.
RB1	34	37	9	10	I/O	TTL	Digital I/O.
RB2	35	38	10	11	I/O	TTL	Digital I/O.
RB3/PGM	36	39	11	12		TTL	
RB3					I/O		Digital I/O.
PGM					I		Low-voltage ICSP programming enable pin.
RB4	37	41	14	14	I/O	TTL	Digital I/O.
RB5	38	42	15	15	I/O	TTL	Digital I/O.
RB6/PGC	39	43	16	16		TTL/ST[2]	
RB6					I/O		Digital I/O.
PGC					I		In-circuit debugger and ICSP programming clock.
RB7/PGD	40	44	17	17		TTL/ST[2]	
RB7					I/O		Digital I/O.
PGD					I/O		In-circuit debugger and ICSP programming data.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured in RC Oscillator mode and a CMOS input otherwise.

11.0 ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the 40/44-pin devices.

The conversion of an analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of V_{DD}, V_{SS}, RA2 or RA3.

The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D clock must be derived from the A/D's internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADCON0 register, shown in Register 11-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 11-2, configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

Additional information on using the A/D module can be found in the PICmicro® Mid-Range MCU Family Reference Manual (DS33023).

REGISTER 11-1: ADCON0 REGISTER (ADDRESS 1Fh)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit 7							bit 0

bit 7-6 **ADCS1:ADCS0:** A/D Conversion Clock Select bits (ADCON0 bits in bold)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	**00**	$F_{OSC}/2$
0	**01**	$F_{OSC}/8$
0	**10**	$F_{OSC}/32$
0	**11**	F_{RC} (clock derived from the internal A/D RC oscillator)
1	**00**	$F_{OSC}/4$
1	**01**	$F_{OSC}/16$
1	**10**	$F_{OSC}/64$
1	**11**	F_{RC} (clock derived from the internal A/D RC oscillator)

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits

000 = Channel 0 (AN0)
001 = Channel 1 (AN1)
010 = Channel 2 (AN2)
011 = Channel 3 (AN3)
100 = Channel 4 (AN4)
101 = Channel 5 (AN5)
110 = Channel 6 (AN6)
111 = Channel 7 (AN7)

Note: The PIC16F873A/876A devices only implement A/D channels 0 through 4; the unimplemented selections are reserved. Do not select any unimplemented channels with these devices.

bit 2 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit

When ADON = 1:
1 = A/D conversion in progress (setting this bit starts the A/D conversion which is automatically cleared by hardware when the A/D conversion is complete)
0 = A/D conversion not in progress

bit 1 **Unimplemented:** Read as '0'

bit 0 **ADON:** A/D On bit

1 = A/D converter module is powered up
0 = A/D converter module is shut-off and consumes no operating current

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

REGISTER 11-2: ADCON1 REGISTER (ADDRESS 9Fh)

R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

bit 7 **ADFM:** A/D Result Format Select bit

1 = Right justified. Six (6) Most Significant bits of ADRESH are read as '0'.
0 = Left justified. Six (6) Least Significant bits of ADRESL are read as '0'.

bit 6 **ADCS2:** A/D Conversion Clock Select bit (ADCON1 bits in shaded area and in bold)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	00	FOSC/2
0	01	FOSC/8
0	10	FOSC/32
0	11	FRC (clock derived from the internal A/D RC oscillator)
1	00	FOSC/4
1	01	FOSC/16
1	10	FOSC/64
1	11	FRC (clock derived from the internal A/D RC oscillator)

bit 5-4 **Unimplemented:** Read as '0'

bit 3-0 **PCFG3:PCFG0:** A/D Port Configuration Control bits

PCFG <3:0>	AN7	AN6	AN5	AN4	AN3	AN2	AN1	AN0	VREF+	VREF-	C/R
0000	A	A	A	A	A	A	A	A	VDD	VSS	8/0
0001	A	A	A	A	VREF+	A	A	A	AN3	VSS	7/1
0010	D	D	D	A	A	A	A	A	VDD	VSS	5/0
0011	D	D	D	A	VREF+	A	A	A	AN3	VSS	4/1
0100	D	D	D	D	A	D	A	A	VDD	VSS	3/0
0101	D	D	D	D	VREF+	D	A	A	AN3	VSS	2/1
011x	D	D	D	D	D	D	D	D	—	—	0/0
1000	A	A	A	A	VREF+	VREF-	A	A	AN3	AN2	6/2
1001	D	D	A	A	A	A	A	A	VDD	VSS	6/0
1010	D	D	A	A	VREF+	A	A	A	AN3	VSS	5/1
1011	D	D	A	A	VREF+	VREF-	A	A	AN3	AN2	4/2
1100	D	D	D	A	VREF+	VREF-	A	A	AN3	AN2	3/2
1101	D	D	D	D	VREF+	VREF-	A	A	AN3	AN2	2/2
1110	D	D	D	D	D	D	D	A	VDD	VSS	1/0
1111	D	D	D	D	VREF+	VREF-	D	A	AN3	AN2	1/2

A = Analog input D = Digital I/O
C/R = # of analog input channels/# of A/D voltage references

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared x = Bit is unknown

Note:	On any device Reset, the port pins that are multiplexed with analog functions (ANx) are forced to be an analog input.

The ADRESH:ADRESL registers contain the 10-bit result of the A/D conversion. When the A/D conversion is complete, the result is loaded into this A/D Result register pair, the GO/$\overline{\text{DONE}}$ bit (ADCON0<2>) is cleared and the A/D interrupt flag bit ADIF is set. The block diagram of the A/D module is shown in Figure 11-1.

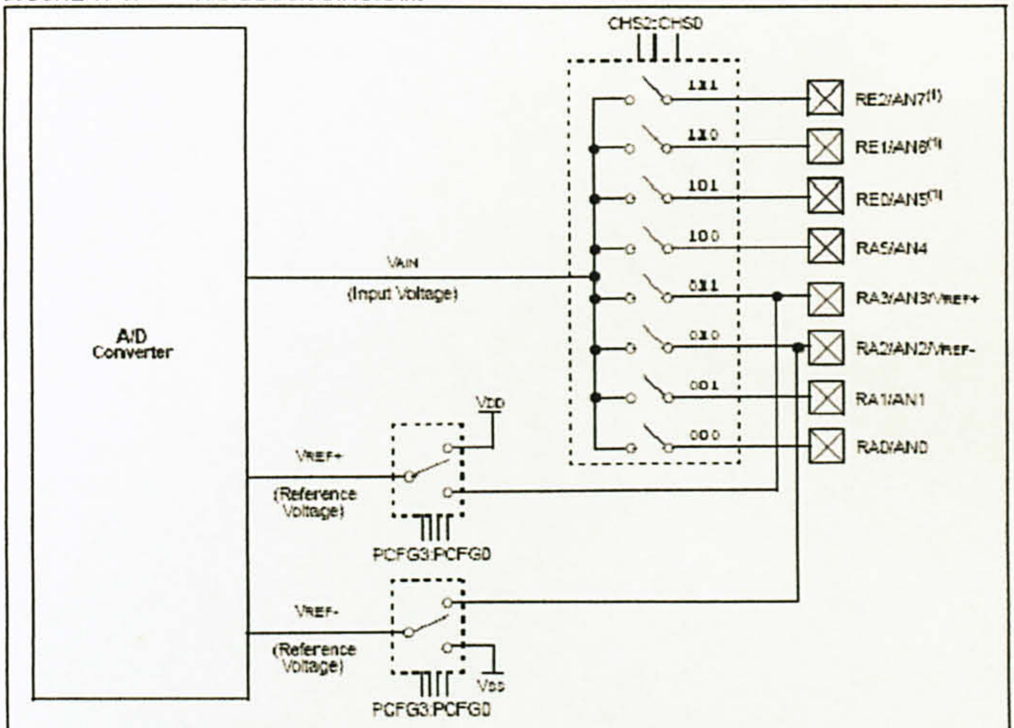
After the A/D module has been configured as desired, the selected channel must be acquired before the conversion is started. The analog input channels must have their corresponding TRIS bits selected as inputs.

To determine sample time, see **Section 11.1 "A/D Acquisition Requirements"**. After this acquisition time has elapsed, the A/D conversion can be started.

To do an A/D Conversion, follow these steps:

1. Configure the A/D module:
   - Configure analog pins/voltage reference and digital I/O (ADCON1)
   - Select A/D input channel (ADCON0)
   - Select A/D conversion clock (ADCON0)
   - Turn on A/D module (ADCON0)
2. Configure A/D interrupt (if desired):
   - Clear ADIF bit
   - Set ADIE bit
   - Set PEIE bit
   - Set GIE bit
3. Wait the required acquisition time.
4. Start conversion:
   - Set GO/$\overline{\text{DONE}}$ bit (ADCON0)
5. Wait for A/D conversion to complete by either:
   - Polling for the GO/$\overline{\text{DONE}}$ bit to be cleared (interrupts disabled); OR
   - Waiting for the A/D interrupt
6. Read A/D Result register pair (ADRESH:ADRESL), clear bit ADIF if required.
7. For the next conversion, go to step 1 or step 2 as required. The A/D conversion time per bit is defined as T_{AD}.

FIGURE 11-1: A/D BLOCK DIAGRAM



Note 1: Not available on 28-pin devices.

11.1 A/D Acquisition Requirements

For the A/D converter to meet its specified accuracy, the charge holding capacitor (C_{HOLD}) must be allowed to fully charge to the input channel voltage level. The analog input model is shown in Figure 11-2. The source impedance (R_S) and the internal sampling switch impedance (R_{SS}) directly affect the time required to charge the capacitor C_{HOLD}. The sampling switch (R_{SS}) impedance varies over the device voltage (V_{DD}); see Figure 11-2. **The maximum recommended impedance for analog sources is 2.5 kΩ.** As the impedance is decreased, the acquisition time may be decreased. After the analog input channel is selected (changed), this acquisition must be done before the conversion can be started.

To calculate the minimum acquisition time, Equation 11-1 may be used. This equation assumes that 1/2 LSb error is used (1024 steps for the A/D). The 1/2 LSb error is the maximum error allowed for the A/D to meet its specified resolution.

To calculate the minimum acquisition time, T_{ACQ}, see the PICmicro® Mid-Range MCU Family Reference Manual (DS33023).

EQUATION 11-1: ACQUISITION TIME

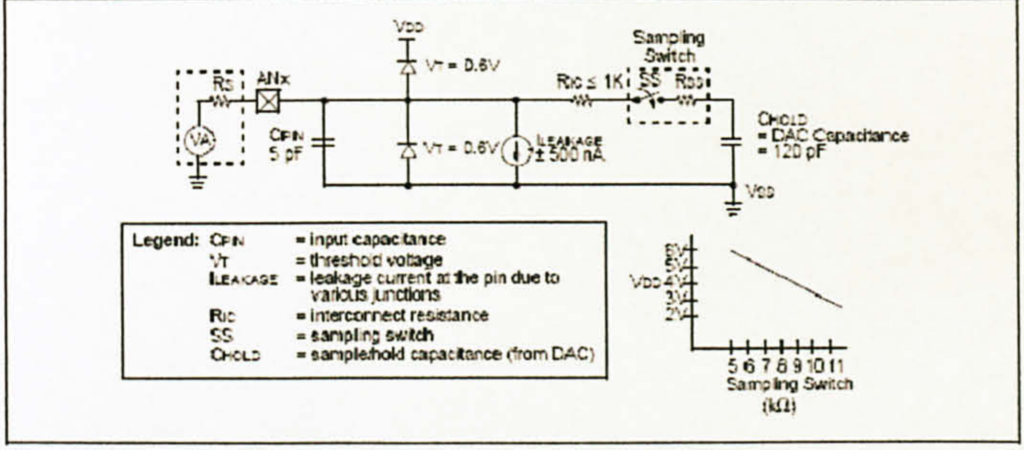
$$
\begin{aligned}
T_{ACQ} &= \text{Amplifier Settling Time} + \text{Hold Capacitor Charging Time} + \text{Temperature Coefficient} \\
&= T_{AMP} + T_C + T_{COFF} \\
&= 2\,\mu s + T_C + [(\text{Temperature} - 25^\circ C)(0.05\,\mu s/^\circ C)] \\
T_C &= C_{HOLD}\,(R_{IC} + R_{SS} + R_S)\,\ln(1/2047) \\
&= -120\,pF\,(1\,k\Omega + 7\,k\Omega + 10\,k\Omega)\,\ln(0.0004885) \\
&= 16.47\,\mu s \\
T_{ACQ} &= 2\,\mu s + 16.47\,\mu s + [(50^\circ C - 25^\circ C)(0.05\,\mu s/^\circ C)] \\
&= 19.72\,\mu s
\end{aligned}
$$

Note 1: The reference voltage (V_{REF}) has no effect on the equation since it cancels itself out.

2: The charge holding capacitor (C_{HOLD}) is not discharged after each conversion.

3: The maximum recommended impedance for analog sources is 2.5 kΩ. This is required to meet the pin leakage specification.

FIGURE 11-2: ANALOG INPUT MODEL



11.2 Selecting the A/D Conversion Clock

The A/D conversion time per bit is defined as TAD. The A/D conversion requires a minimum 12 TAD per 10-bit conversion. The source of the A/D conversion clock is software selected. The seven possible options for TAD are:

- 2 Tosc
- 4 Tosc
- 8 Tosc
- 16 Tosc
- 32 Tosc
- 64 Tosc
- Internal A/D module RC oscillator (2-6 µs)

For correct A/D conversions, the A/D conversion clock (TAD) must be selected to ensure a minimum TAD time of 1.6 µs.

Table 11-1 shows the resultant TAD times derived from the device operating frequencies and the A/D clock source selected.

11.3 Configuring Analog Port Pins

The ADCON1 and TRIS registers control the operation of the A/D port pins. The port pins that are desired as analog inputs must have their corresponding TRIS bits set (input). If the TRIS bit is cleared (output), the digital output level (VOH or VOL) will be converted.

The A/D operation is independent of the state of the CHS2:CHS0 bits and the TRIS bits.

Note 1:	When reading the port register, any pin configured as an analog input channel will read as cleared (a low level). Pins configured as digital inputs will convert an analog input. Analog levels on a digitally configured input will not affect the conversion accuracy.
2:	Analog levels on any pin that is defined as a digital input (including the AN7:AN0 pins) may cause the input buffer to consume current that is out of the device specifications.

TABLE 11-1: TAD vs. MAXIMUM DEVICE OPERATING FREQUENCIES (STANDARD DEVICES (F))

AD Clock Source (TAD)		Maximum Device Frequency
Operation	ADCS2:ADCS1:ADCS0	
2 Tosc	000	1.25 MHz
4 Tosc	100	2.5 MHz
8 Tosc	001	5 MHz
16 Tosc	101	10 MHz
32 Tosc	010	20 MHz
64 Tosc	110	20 MHz
RC[1, 2, 3]	x11	(Note 1)

Note 1: The RC source has a typical TAD time of 4 µs but can vary between 2-6 µs.

2: When the device frequencies are greater than 1 MHz, the RC A/D conversion clock source is only recommended for Sleep operation.

3: For extended voltage devices (LF), please refer to **Section 17.0 "Electrical Characteristics"**.

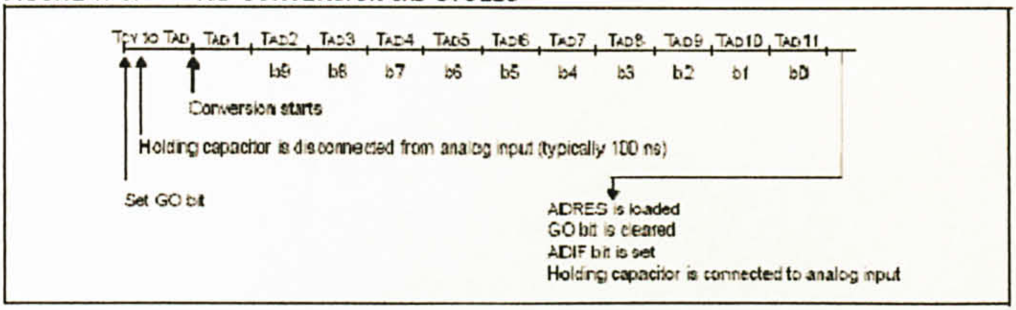
11.4 A/D Conversions

Clearing the GO/$\overline{\text{DONE}}$ bit during a conversion will abort the current conversion. The A/D Result register pair will NOT be updated with the partially completed A/D conversion sample. That is, the ADRESH:ADRESL registers will continue to contain the value of the last completed conversion (or the last value written to the ADRESH:ADRESL registers). After the A/D conversion is aborted, the next acquisition on the selected channel is automatically started. The GO/$\overline{\text{DONE}}$ bit can then be set to start the conversion.

In Figure 11-3, after the GO bit is set, the first time segment has a minimum of TCY and a maximum of TAD.

Note:	The GO/$\overline{\text{DONE}}$ bit should **NOT** be set in the same instruction that turns on the A/D.

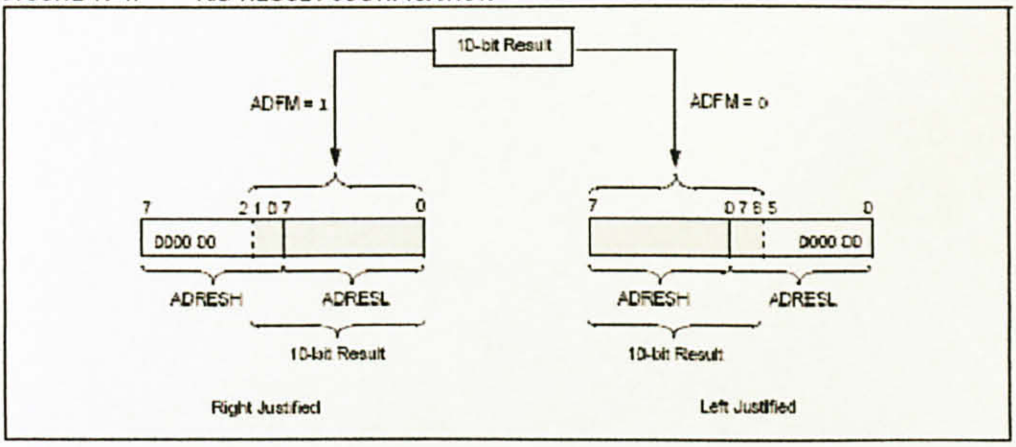
FIGURE 11-3: A/D CONVERSION TAD CYCLES



11.4.1 A/D RESULT REGISTERS

The ADRESH:ADRESL register pair is the location where the 10-bit A/D result is loaded at the completion of the A/D conversion. This register pair is 16 bits wide. The A/D module gives the flexibility to left or right justify the 10-bit result in the 16-bit result register. The A/D Format Select bit (ADFM) controls this justification. Figure 11-4 shows the operation of the A/D result justification. The extra bits are loaded with '0's. When an A/D result will not overwrite these locations (A/D disable), these registers may be used as two general purpose 8-bit registers.

FIGURE 11-4: A/D RESULT JUSTIFICATION

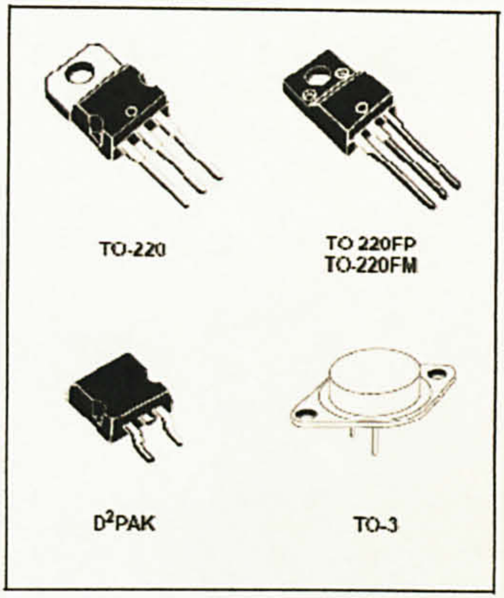


APPENDIX C

L7800 SERIES VOLTAGE REGULATOR

POSITIVE VOLTAGE REGULATORS

- OUTPUT CURRENT TO 1.5A
- OUTPUT VOLTAGES OF 5; 5.2; 6; 8; 8.5; 9; 10; 12; 15; 18; 24V
- THERMAL OVERLOAD PROTECTION
- SHORT CIRCUIT PROTECTION
- OUTPUT TRANSITION SOA PROTECTION



DESCRIPTION

The L7800 series of three-terminal positive regulators is available in TO-220, TO-220FP, TO-220FM, TO-3 and D^{2}PAK packages and several fixed output voltages, making it useful in a wide range of applications. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltage and currents.

Figure 1: Schematic Diagram

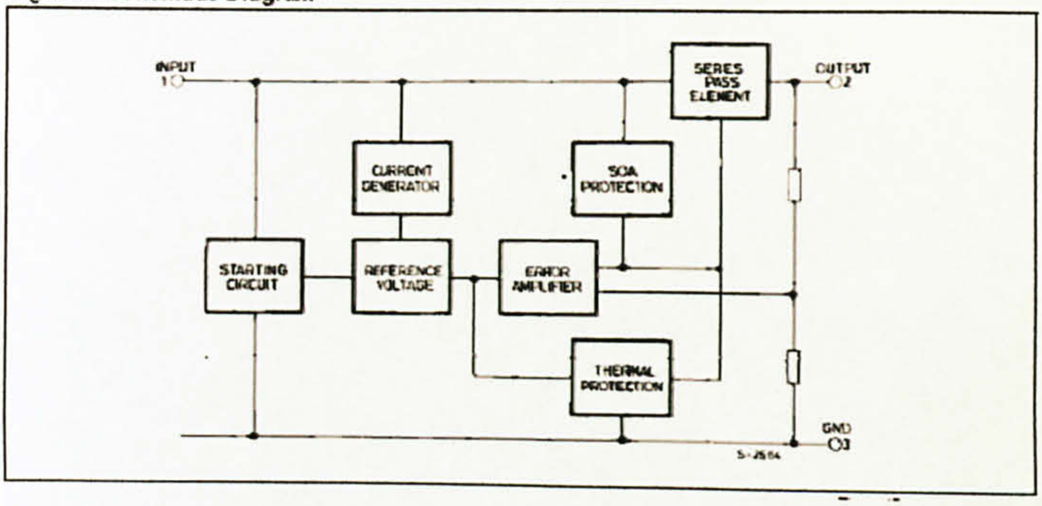


Table 1: Absolute Maximum Ratings

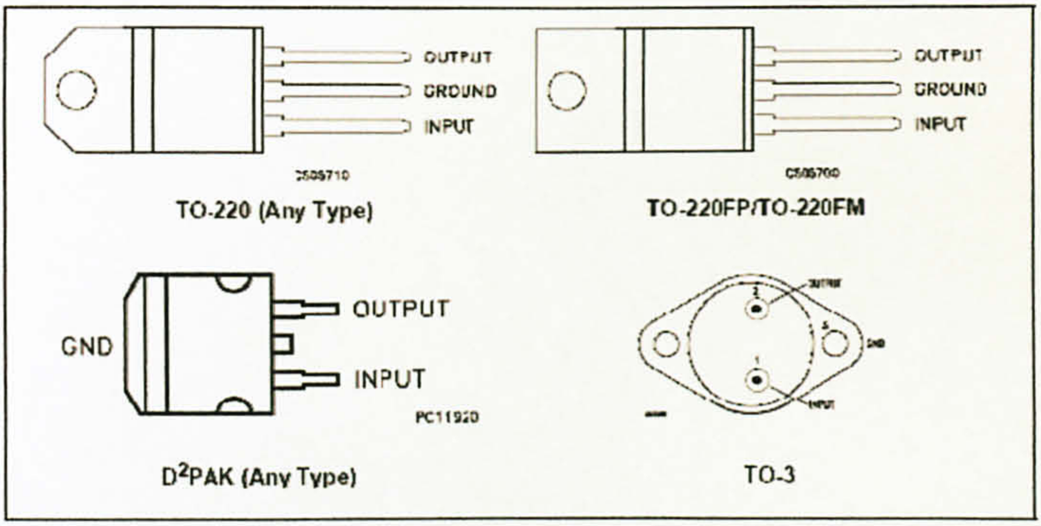
Symbol	Parameter		Value	Unit
V_I	DC Input Voltage	for V_O= 5 to 18V	35	V
		for V_O= 20, 24V	40	
I_O	Output Current		Internally Limited	
P_{tot}	Power Dissipation		Internally Limited	
T_{stg}	Storage Temperature Range		-65 to 150	°C
T_{op}	Operating Junction Temperature Range	for L7800	-55 to 150	°C
		for L7800C	0 to 150	

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.

Table 2: Thermal Data

Symbol	Parameter	D^2PAK	TO-220	TO-220FP	TO-220FM	TO-3	Unit
$R_{thj-case}$	Thermal Resistance Junction-case Max	3	5	5	5	4	°C/W
$R_{thj-amb}$	Thermal Resistance Junction-ambient Max	62.5	50	60	60	35	°C/W

Figure 3: Connection Diagram (top view)



APPENDIX D

LCD DISPLAY (JHD204A)

JHD204A SERIES

CHARACTERISTICS:

DISPLAY CONTENT: 20 CHAR x 4ROW

CHAR. DOTS: 5 x 8

DRIVING MODE: 1/16D

AVAILABLE TYPES:

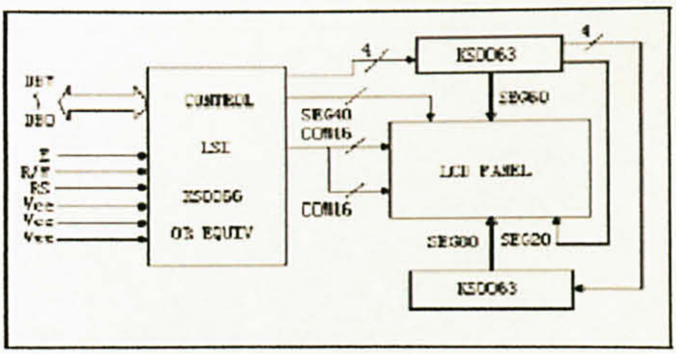
TN、STN(YELLOW GREEN、GREY、B/W)

REFLECTIVE

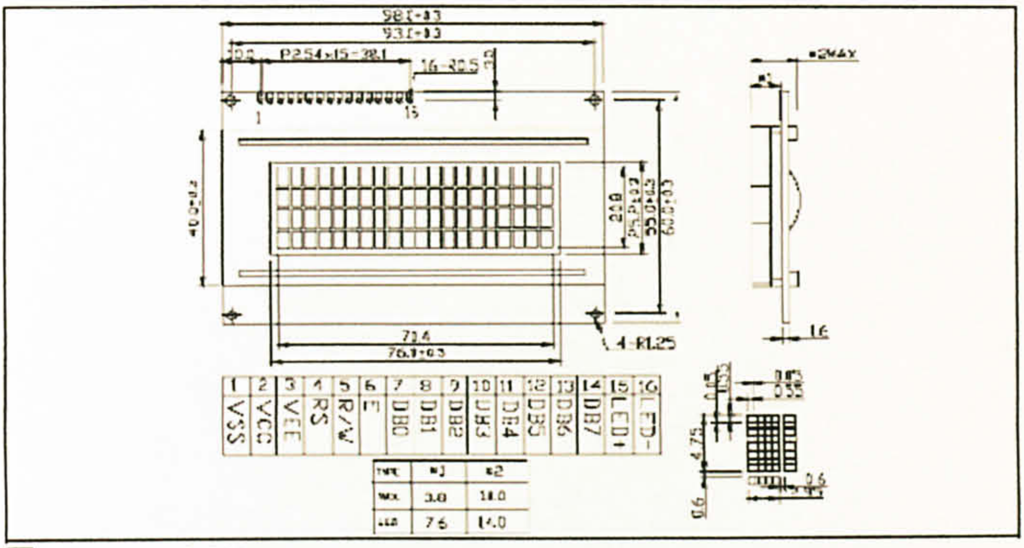
PARAMETER (V_{DD}=5.0V ± 10%, V_{SS}=0V, T_a=25°C)

Parameter	Symbol	Testing Criteria	Standard Values			Unit
			Min.	Typ.	Max	
Supply voltage	V_{DD}-V_{SS}	-	4.5	5.0	5.5	V
Input high voltage	V_{IH}	-	2.2	-	V_{DD}	V
Input low voltage	V_{IL}	-	-0.3	-	0.6	V
Output high voltage	V_{OH}	$-I_{OH}$=02mA	2.4	-	-	V
Output low voltage	V_{OL}	I_{OL}=1.2mA	-	-	0.4	V
Operating voltage	I_{DD}	V_{DD}=5.0V	-	2.0	5.0	mA

APPLICATION CIRCUIT



DIMENSIONS/DISPLAY CONTENT



PIN CONFIGURATION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
VSS	VCC	VEE	RS	R/W	E	DB0	DB1	DB2	DB3	DB4	DB5	DB6	DB7	LED-	LED-

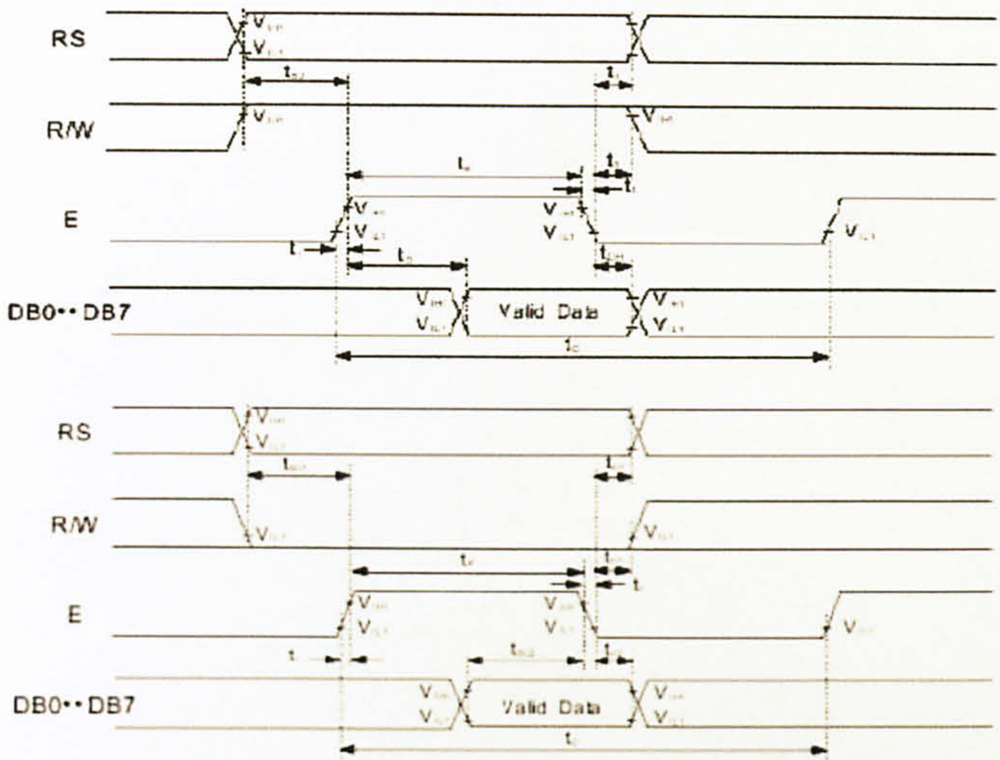
AC Characteristics Read Mode Timing Diagram

Table 12. AC Characteristics (V_{DD} = 4.5V ~ 5.5V, Ta = -30 ~ +85°C)

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R, t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu1	40	-	-	
	R/W and RS Hold Time	t_{H1}	10	-	-	
	Data Setup Time	tsu2	80	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R, t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu	40	-	-	
	R/W and RS Hold Time	t_H	10	-	-	
	Data Output Delay Time	t_D	-	-	120	
	Data Hold Time	t_{DH}	5	-	-	

Table 13. AC Characteristics (V_{DD} =2.7V ~ 4.5V, Ta = -30 ~ +85°C)

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	1000	-	-	ns
	E Rise / Fall Time	$t_R t_F$	-	-	25	
	E Pulse Width (High, Low)	tw	450	-	-	
	R/W and RS Setup Time	tsu1	60	-	-	
	R/W and RS Hold Time	t_{H1}	20	-	-	
	Data Setup Time	tsu2	195	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	1000	-	-	ns
	E Rise / Fall Time	t_R, t_F	-	-	25	
	E Pulse Width (High, Low)	tw	450	-	-	
	R/W and RS Setup Time	tsu	60	-	-	
	R/W and RS Hold Time	t_H	20	-	-	
	Data Output Delay Time	t_D	-	-	360	
	Data Hold Time	t_{DH}	5	-	-	

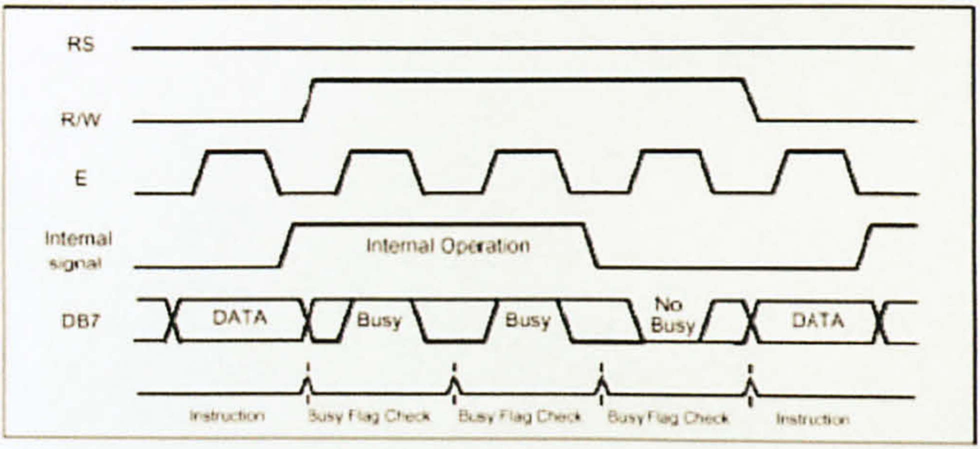


Write Mode Timing Diagram

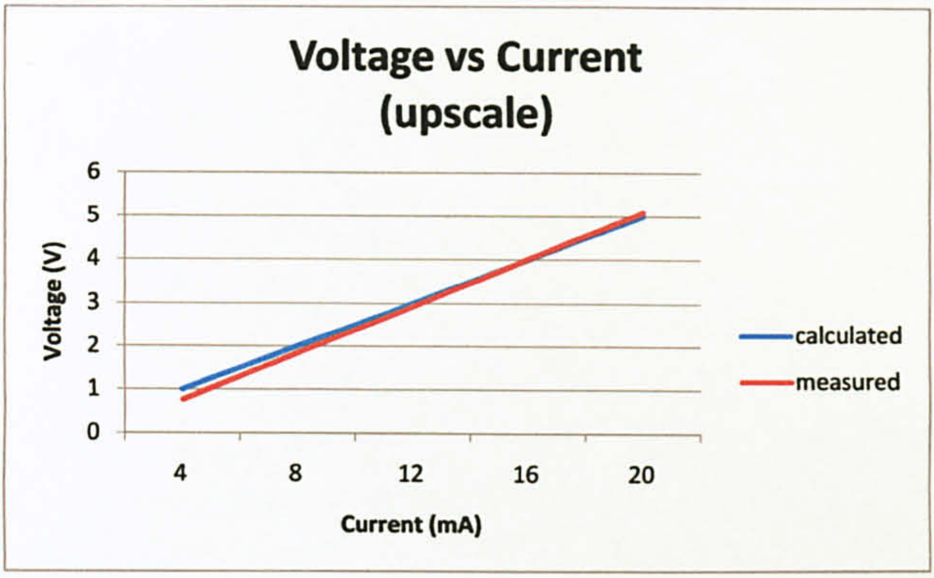
Timing

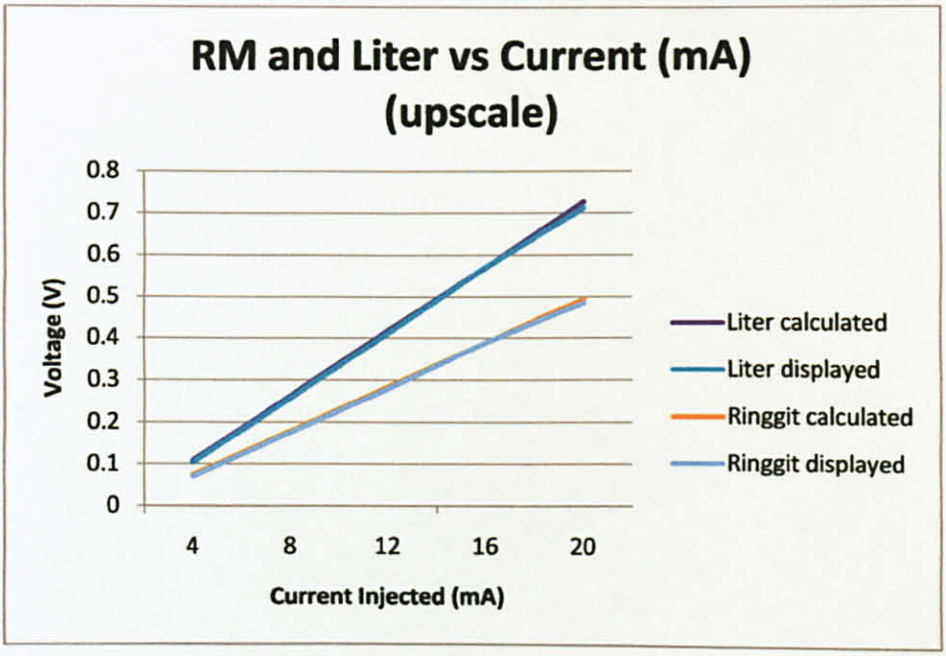
1) Interface with 8-bit MPU

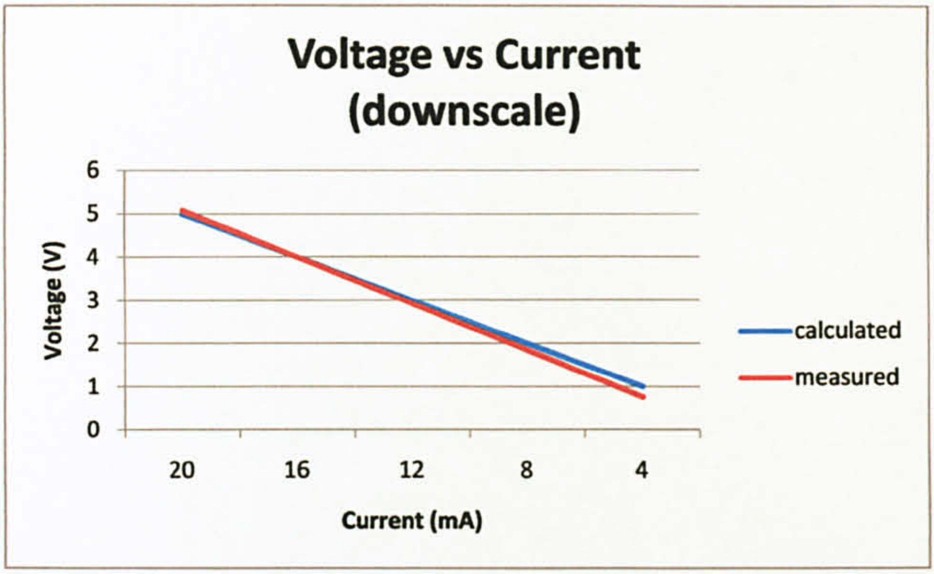
When interfacing data length are 8-bit, transfer is performed at a time through 8 ports, from DB0 to DB7. Example of timing sequence is shown below.

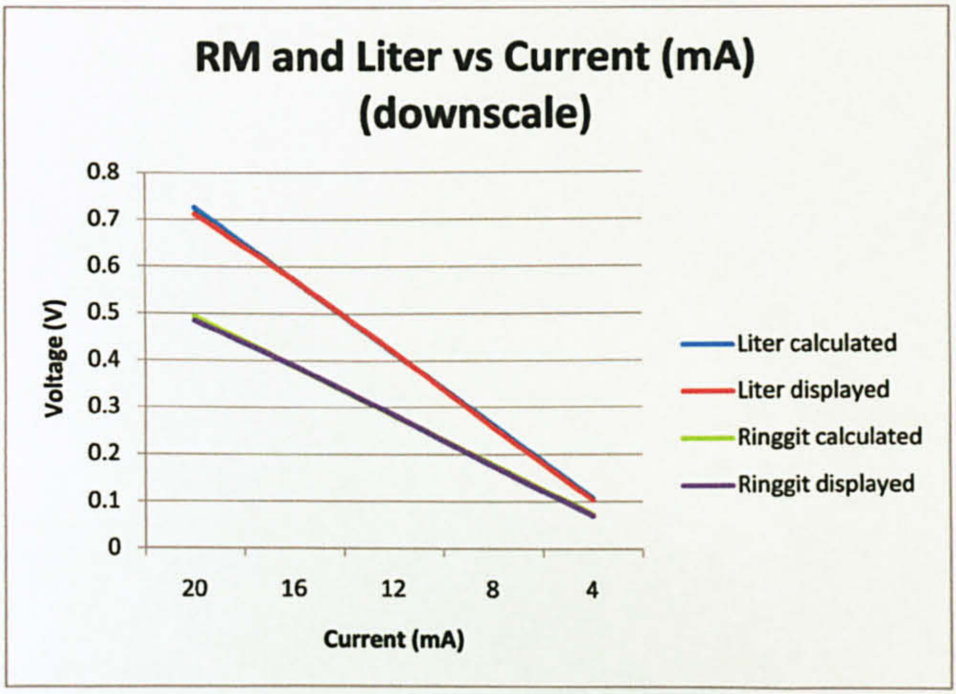


APPENDIX E
GRAPHICAL RESULT






Voltage vs Current (downscale)
6
5
4
3
2
1
0
Voltage (V)
20
16
12
8
4
Current (mA)
calculated
measured


RM and Liter vs Current (mA) (downscale)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Voltage (V)
20
16
12
8
4
Current (mA)
Liter calculated
Liter displayed
Ringgit calculated
Ringgit displayed

APPENDIX F
PROTOTYPE